63-4-5

AIRPORT FACILITIES FOR GENERAL AVIATION

REPORT NO. 1400-1
CONTRACT FAA/BRD-403
November 1962

Prepared for

FEDERAL AVIATION AGENCY
SYSTEMS RESEARCH AND DEVELOPMENT SERVICE
Washington, D. C.

Prepared in cooperation with

PORTER & O'BRIEN
Newark, New Jersey

with Appendix by

Landrum & Brown
Cincinnati, Ohio

CUTLER - HAMMER
AIRBORNE INSTRUMENTS LABORATORY
DEER PARK, LONG ISLAND, NEW YORK
AIL DIVISION

AIRPORT FACILITIES FOR GENERAL AVIATION

by

M. A. Warskow, H. C. Burns, T. Dayton, W. Guidi, and P. H. Stafford

REPORT NO. 1400-1
CONTRACT FAA/BRD-403
PROJECT NO. 412-7R

November 1962

Prepared for

FEDERAL AVIATION AGENCY
SYSTEMS RESEARCH AND DEVELOPMENT SERVICE
Washington, D. C.

Prepared in cooperation with

PORTER & O'BRIEN
Newark, New Jersey

with Appendix by

Landrum & Brown
Cincinnati, Ohio

AIRBORNE INSTRUMENTS LABORATORY
A DIVISION OF CUTLER-HAMMER, INC.

Deer Park, Long Island, New York

This report has been prepared by Airborne Instruments Laboratory for the Systems Research and Development Service, Federal Aviation Agency, Research Division, under Contract FAA/BRD-403. The contents of this report reflect the views of the contractor, who is responsible for the facts and the accuracy of the data presented herein, and do not necessarily reflect the official views or policy of the FAA.

FOREWORD

This study was divided into five tasks. Tasks 1 and 2 involved the development of planning criteria; Tasks 3, 4, and 5 involved checking the criteria by application to actual situations (Washington, D. C., and Lambert-St. Louis airports). Since the Washington, D. C. work was subsequently expanded to involve the FAA Services, the application of these criteria to the Washington, D. C. area are included in a report now being prepared by the FAA. Thus, the checking of the criteria against actual situations has been completed though the report on the applications is only included in part herein. The Washington area work also required expansion of the team to include the firms of Landrum and Brown and Paul Stafford Associates. The expanded Washington area effort included additional planning guides that are included herein as Chapters 8 and 9, and the Appendix.

ABSTRACT

Several criteria relating to the handling of general aviation on airports have been developed. In many cases, modifications of existing criteria are suggested. These include the subjects of runway-length corrections, instrument-approach needs, airspace needs, annual capacity of airports, guidance for planning separate runway facilities for general aviation, procedures for performing economic analyses, and the effects of airport accessibility.

The study has concentrated on planning for general aviation in metropolitan areas. Observations of general-aviation operations at air-carrier and general-aviation airports have indicated that new criteria for determining the numbers of airports required in metropolitan areas are needed. In developing regional plans and individual airport plans, the importance of using a cost-versus-benefit economic analysis is stressed.

The criteria developed have been tested by applying them to the Lambert-St. Louis airport and to regional planning for the Washington, D. C. area.

TABLE OF CONTENTS

		Page
	Foreword	i
	Abstract	iii
I.	Introduction	1-1
II.	Conclusions and Recommendations	2-1
III.	General-Aviation Airports--Their Number, Ownership, and Regional Planning	3-1
IV.	Layouts of General-Aviation Airports	4-1
	A. Runway Length and Corrections	4-1
	B. Effect of Crosswinds	4-10
	C. Effect of Noise in Landing and Takeoff Operations	4-12
	D. Annual Capacity of General-Aviation Airports	4-12
	E. Runway, Terminal, and Service Facilities	4-22
V.	General Aviation at Air-Carrier Airports	5-1
	A. Layouts of Air-Carrier Airports for General Aviation	5-2
	B. Length of Secondary Parallel Runway	5-3
	C. Practicality of Separate Facilities	5-7
VI.	Airspace and Navaid Requirements	6-1
	A. Airspace Requirements and Airport Location	6-1
	B. Pilot Aids	6-5
	C. Instrument-Approach Equipment	6-6
VII.	Criteria Used at Lambert-St. Louis Airport	7-1
	A. Application of Capacity Criteria	7-1
	B. Application of Criteria for Performing Detailed Capacity and Economic Analysis	7-2

		Page
VIII.	Economics of Airports and Ground Transportation	8-1
	A. Airport Costs	8-4
	B. Airport Income	8-5
IX.	Potential General-Aviation Air Traffic	9-1
X.	References	10-1
	Appendix--Determination of Potential General-Aviation Air Traffic	

LIST OF ILLUSTRATIONS

Figure	
4-1	Correction Factors for Runways at General-Aviation Airports
4-2	Takeoff/Landing Distance Required for Currently Active General-Aviation Aircraft Over 50-Foot Obstacle
4-3	Takeoff/Landing Distance Required for Miscellaneous General-Aviation Aircraft Over 50-Foot Obstacle
4-4	Relation Between Distance and Temperature at Sea Level for Takeoff and Landing Over 50-Foot Obstacle for Various Models of Aircraft
4-5	Increase in Distance Due to Temperature at Sea Level for Takeoff Over 50-Foot Obstacle for Various Models of Aircraft
4-6	Effect of Airport Elevation on Required Takeoff Distance Over 50-Foot Obstacle
4-7	Effect of Airport Elevation on Climb-Out Angle
4-8	Accelerate-Stop Distance at Sea Level for Typical General-Aviation Aircraft
4-9	Runway Length Required by Aircraft During 2000 Successive Operations at Washington National Airport
4-10	Variation of Practical Hourly Runway Capacity with Average Delay on Runways Handling Only Type C, D, and E Aircraft
4-11	Analysis of Hourly Operating Rate at Ten General-Aviation Airports in Washington, D. C. Area on 28 and 29 October 1961
4-12	Analysis of Hourly Operating Rate at Pal Waukee Airport, Illinois from 20 to 22 July 1956
4-13	Analysis of Hourly Operating Rate at Fullerton Airport, California from 27 to 29 July 1956
4-14	Analysis of Hourly Operating Rate at Flying Cloud Airport, Minnesota from 22 to 24 June 1962
4-15	Analysis of Hourly Operating Rate at Crystal Airport, Minnesota from 22 to 24 June 1962

Figure

4-16 Operations Occurring During Peak Hour Related to Total Daily Operations

4-17 Relation of Itinerant General-Aviation to Air-Carrier Instrument Approaches for Fiscal Year 1961 at Airports Where Itinerant General-Aviation Operations Exceed Both Air-Carrier and 50,000 Operations Per Year

4-18 Airport for Single-Engine and Training Aircraft

4-19 General-Aviation Airport

4-20 General-Aviation and Training Airport

4-21 General-Aviation Airport with Parallel Runways

4-22 Airport for Local Service and General Aviation

5-1 Parallel-Runway and Terminal Locations for General Aviation on Air-Carrier Airports

5-2 Secondary-Runway Length for Maximum Capacity

5-3 10,000- and 6000-Foot Runways with 5000-Foot Separation

5-4 8000- and 5000-Foot Runways with 1000-Foot Separation

5-5 6000- and 3500-Foot Runways with 700-Foot Separation

5-6 10,000-, 6000-, and 2200-Foot Runways

5-7 8000- and 5000-Foot Runways and Two 10,000-Foot Runways

6-1 Plan View of IFR Airspace Requirement

6-2 Application of IFR Airspace Criteria to Washington Plan C Airports

7-1 Lambert-St. Louis Municipal Airport with 1962 Runway Configuration with Additional Taxiways--Plan A

7-2 Typical Work Sheet for Airport Observations

7-3 Lambert-St. Louis Municipal Airport with Added 3500-Foot Parallel Runway--Plan B

7-4 Lambert-St. Louis Municipal Airport with Added 4600-Foot Parallel Runway--Plan C

7-5 Lambert-St. Louis Municipal Airport with Added 6000-Foot Parallel Runway--Plan D

Figure

7-6	Priority of Runway Use
7-7	Delay Resulting from Various Runway Operating Rates for Plan C and Priority 3
7-8	Summary of Predicted Airport Capacity for 1970
8-1	Costs of Travel to Airport
8-2	Travel and Airport Costs
8-3	Airport Costs
8-4	Airport Income
8-5	Airport Income vs Cost

LIST OF TABLES

Table		Page
4-I	Landing or Takeoff Distance (Whichever is Greater) Over 50-Foot Obstacle--Currently Active Aircraft	4-3
4-II	Landing or Takeoff Distance (Whichever is Greater) Over 50-Foot Obstacle--Miscellaneous Aircraft	4-7
4-III	Calculation of Annual Capacity of General-Aviation Airports	4-13
4-IV	Annual Operations at Selected General-Aviation Airports	4-16
4-V	Amount of Touch-and-Go Traffic During Peak Capacity Hours at Two General-Aviation Airports for 1960	4-18
5-I	Airport Capacity as a Function of Secondary-Runway Length	5-4
7-I	Percent Distribution of Aircraft Operations at Lambert Field, St. Louis During Peak 5-Hour Period for 7, 8, and 10 June	7-3
7-II	Estimated Aircraft Operations at Lambert Field, St. Louis for 1970	7-5
7-III	Estimated Aircraft Operations at Lambert Field, St. Louis for Weekday in Summer 1970	7-6
7-IV	Estimated Aircraft Operations at Lambert Field, St. Louis for Sunday in Summer 1970	7-7
7-V	Comparison of Lambert Analysis with Planning Criteria	7-9
7-VI	Summary of Plan C Annual Operating Costs for 1970	7-11
7-VII	Summary of Annual Operating Costs for 1970	7-12
7-VIII	Capital Improvement Costs	7-14
7-IX	Annual Costs	7-16
7-X	Benefit-Cost Ratios	7-17
8-I	Airport Income Dollars per Based Aircraft	8-6

I. INTRODUCTION

In June 1961, Airborne Instruments Laboratory (AIL) was awarded a contract to develop criteria to guide the planning and construction of general-aviation airports and air-carrier airports accommodating general aviation. Emphasis was to be placed on the planning of airports in metropolitan areas and, in particular, on assessing the value of using separate facilities (including separate runways) for general aviation at an air-carrier airport.

AIL analyzed the new criteria using the capacity and economic-analysis techniques developed under Contract FAA/BRD-136. The study also required an investigation of the general-aviation operations in four metropolitan areas having a large volume of general-aviation traffic; these areas were Chicago, Illinois; Minneapolis, Minnesota; Dallas, Texas; and Phoenix, Arizona. Because AIL is located near New York City, general-aviation operations in the New York area were also studied. Data obtained in other projects (references 1 and 2) were found to be pertinent to this study.

When the study phase was concluded, the criteria that were developed were tested by applying them to two airport areas.

1. A separate general-aviation runway being constructed at Lambert-St. Louis was analyzed.
2. A regional plan for general aviation in the Washington, D. C. area was developed.

The firm of Porter and O'Brien provided consulting engineering services to AIL.

The study of the Washington, D. C. area was expanded to include all of the airports and heliports in that area (reference 3). The firms of Landrum and Brown and Paul Stafford Associates assisted AIL in this phase of the project.

II. CONCLUSIONS AND RECOMMENDATIONS

1. Regional planning should be encouraged in metropolitan areas to provide airport facilities that:

   a. Serve the public interest,

   b. Have adequate economic stature,

   c. Are compatible with airspace requirements,

   d. Are coordinated with other phases of metropolitan area planning.

The FAA should encourage and assist planning for airport needs on a regional basis.

2. The regional airport plan should include air-carrier, military, and general-aviation airports; the development of general aviation at air-carrier airports should be encouraged to the extent that it does not compromise essential air carrier needs, and to make more efficient use of the capacity of the airport.

3. In general, an excessive number of airports in metropolitan areas results in inadequate facilities and poor use of airspace. Instead, airports are needed that serve an area large enough to permit the development of adequate facilities but also have reasonable accessibility, and that are located so that the airspace is efficiently used. In metropolitan areas where planning is done on this basis each general-aviation airport should be planned to provide for growth from between 50 and 150 based aircraft to between 150 and 500 based aircraft.

4. In metropolitan areas, airports should be regarded as public utilities and their locations should be selected so that they serve a population area without unnecessary competition and have a high enough level of activity to provide an adequate and economic operation.

5. General-aviation airports should generally be owned or controlled by the public to ensure their perpetuity. If private airports are to remain a part of the regional system, their perpetuity should be ensured through agreement with the local governmental units before they are eligible for federal support, navaids, or other public assistance.

6. Except for special circumstances of wind and topography, general-aviation airports should have a single runway or two parallel runways.

7. The annual capacity of general-aviation airports with a single runway is about 165,000 to 200,000 operations varying with the factors of runway layout and types of aircraft.

8. For general-aviation airports, runway-length corrections for elevation, temperature and gradient should be revised to reflect aircraft performance more accurately.

9. Planning criteria for justification of additional runways to provide greater capacity at general-aviation airports should be based on economic analysis of benefits versus costs.

10. The building area for general aviation should provide room for an administration building, service hangars, individual hangars, transient-aircraft parking apron, tie-down storage area, and automobile-parking lots, and preferably should be located on one side of the runway.

11. For actual parking, tie-down, or storage (including maneuvering space), each aircraft will require 3000 to 4500 square feet, permitting 10 to 15 aircraft per acre.

12. Automobile-parking space should provide for about two cars per based aircraft at the rate of 100 cars per acre with an overflow area for special occasions. Activity surveys of existing airports will give more accurate data for specific sites.

13. As an example, if one estimates the maximum number of transient aircraft to be accommodated as 50 percent of the number of based aircraft, the space required will be as follows:

Number of Based Aircraft	Aircraft Area (acres)	Automobile Area (acres)
100	10 to 15	2 to 3
400	40 to 60	8 to 12

14. The provision of separate facilities for general aviation, apart from air-carrier facilities on an air-carrier airport, should be determined on the basis of economic analysis. The separation of heavy aircraft from light aircraft during landing and takeoff is a desirable but not a determining factor.

15. It is practical to increase the capacity of an airport by providing a separate secondary runway for general aviation; this increase can be predicted.

16. The optimum length of the secondary runway varies with the aircraft population. For aircraft populations with less than about 2/3 jet and heavy propeller aircraft, a secondary runway shorter than the main runway will provide an overall capacity at least as high as two parallel runways of equal length. For traffic-control reasons, when selecting the length, the secondary runway should either be less than about 2/3 the primary runway length or equal to the primary-runway length. The length most beneficial to a specific case should be determined by applying economic analysis.

17. To provide for IFR operations, airports should be located with their instrument runways parallel and with an airspace reservation of 10 by 30 miles for all-carrier airports and 8 by 20 miles for airports serving only light twin engine or smaller aircraft.

18. General-aviation airports in metropolitan areas should provide minimum pilot aids for safety and convenience--unicom, weather information, ATC flight-plan filing, NOTAMS, restaurant, and pilot lounge.

19. In a metropolitan airport system, general-aviation airports that accommodate 50 or more based aircraft should have instrument-approach procedures.

20. The criteria for establishing landing aids and control tower facilities for airports should be reviewed to establish an economic basis for their application.

21. The accessibility to potential aircraft owners of airports accommodating general-aviation traffic has a measurable effect on the volume of ownership that will result.

22. The criteria developed in this study should be incorporated into FAA planning and design standards.

III. GENERAL-AVIATION AIRPORTS-- THEIR NUMBER, OWNERSHIP, AND REGIONAL PLANNING

AIL has studied the conclusions in the FAA report "Economic Planning for General Aviation Airports" (reference 4) on the criteria for establishing airports. We have also reviewed the current "National Airport Plan" (reference 5) and its planning and policies (reference 6). Our experience indicates that there may be good reason to modify these criteria. Our general conclusions apply principally to metropolitan areas that can be classed as large- or medium-traffic hubs (FAA Hub System of Community Classification). However, the basic philosophy also applies to other communities.

Observations of general-aviation operations were made at the following types of airports:

1. Airports in the major metropolitan areas of Dallas, Texas; Phoenix, Arizona; Minneapolis, Minnesota; Chicago, Illinois; Washington, D. C.; and New York City, New York.
2. Airports with only a few based aircraft and a low activity.
3. Busy general-aviation and air-carrier airports.

It was concluded that the number of airports needed to serve general aviation in the large- and medium-hub areas should be determined on the basis of selecting airport locations such that each airport serves a geographical area large enough to permit the airport to attain a reasonable economic level. In addition, the size of the area to be served must be limited so that the airport is reasonably accessible to potential users. In large metropolitan areas, this will result in relatively few, but well-developed airports. This situation is desirable because an airport cannot provide adequate services unless it has a sufficient number of based aircraft and annual operations.

In general, regional planning to provide an economically promising airport program will also help to alleviate airspace problems because the general-aviation airport that caters to itinerant operations should have the minimum IFR capability. This IFR capability is most easily attained when the airports to be served are located so that they are not too close to one another.

In developing the airport plan for a large metropolitan area, the entire airport complex should be considered, including the air-carrier and military airports. Where the demand exists and the airspace permits, each air-carrier airport should be developed to its maximum potential to serve both air-carrier and general aviation through use of efficient runway and facility layouts. It may be practical to provide separate facilities for general aviation at air-carrier airports. This would obviously enhance the economic well-being of any major airport through the greater concentration of operations and, therefore, service facilities that can be provided. The need to provide general-aviation facilities at air-carrier airports will remain and may increase because of the need to interchange passengers between air-carrier and general aviation. Developing existing airports to their maximum efficiency should not, however, be used to discourage regional planning and the selection of airport sites for future needs.

To determine the number of general-aviation airports needed in addition to air-carrier airports, economic and airspace needs should again be major considerations. An FAA publication (reference 4) on economic planning suggests, "In metropolitan areas, the neighborhood with 10 aircraft owners justifies an airport if no suitable one exists within a 10-mile or 30-minute driving time. A busy air-carrier airport is not usually suitable for general aviation." In some instances a better measure than driving time alone is the "distance/time reference," which is defined as the sum of the distance to the airport in miles and the average driving time in minutes. Although other measures are involved such as airspace, economics, etc., the distance/time reference generally should not exceed 45. A more thorough method of determining the effect of accessibility is described in the Appendix to this report. Further, using 10 based aircraft as a basis for determining airport location in a metropolitan area seems to be far too low a level to provide any reasonable measure of economic stability. Although the actual minimum level of based aircraft will vary with the locality, land cost, etc., it would appear to be more on the order of 50 to 100 based aircraft (Chapter 8 amplifies this), and we would suggest that this criteria be revised upward to provide more realistic planning criteria.

Airport facilities should be developed to: (1) replace existing facilities, (2) provide for growth in activities, and (3) meet demands not presently fulfilled in the area. (The need for a facility is not created by constructing it.) To a large extent, planning on this basis permits a realistic rather than an academic approach to the measurement of demands for services and facilities. As in other forms of transportation, the activity at any location will consist of (a) existing, plus (b) diverted, plus (c) normal growth, plus (d) induced

growth. Reasonable forecasts of demand can be made by competent specialists using survey data and proven methods. Economic measures as with benefit-cost analysis should be applied in regional planning to ensure a sound development program.

The revised criteria suggested herein will have the beneficial effect of locating airports far enough apart so that they do not offer duplicate facilities to the same customer. The airport should be viewed as a public utility with a responsibility to provide a reasonable level of service.

The general principle of using an economic measure to guide airport development has application in the small or non-hub areas. In these areas, it may be possible to have one airport serving more than one community by using the ground-travel-time criteria for airport location. This airport would generally serve scheduled air-carrier traffic as well as general aviation. The economic analyses used to plan regional airports should include all aspects of benefits and costs to ensure that the public interest is served.

To establish airports on the basis of these principles, there must be a certain amount of centralized planning. If the metropolitan-area plan for general aviation can be guided by an organization that can view the entire metropolitan region, and the actual development of the program agrees with the recommended regional plan, good planning for the future can be accomplished. It is important that the developers of the regional plan devise practical means of implementing the plan.

One important aspect of regional planning is airport ownership. We have observed capably directed, busy operations at both private and public general-aviation airports. However, the private-airport operation is generally less stable, principally because of economic pressures that are not as pertinent to public operation. These economic pressures include:

1. Need to ensure a profit on an original investment. This may be through appreciation of land value rather than on the airport operation. If this is the case, then the airport will exist only until the land value makes it worthwhile to dispose of the airport to permit a more profitable use of the land.

2. Inability to economically or legally protect approach areas or prevent the erection of hazards to flight.

3. High cost of real-estate taxes and insurance.

Thus, if a regional plan includes private airports, it must ensure the continued operation of the private airport. This involves approach-protection, instrument-approach, and traffic-control facilities. Either a legal means must be found for ensuring continuous operation and providing public services at a private airport, or steps must be taken to achieve public ownership.

An excellent example of a public organization accomplishing regional planning is the Minneapolis-St. Paul Metropolitan Airports Commission. This Commission was established in 1943 by the state legislature to have jurisdiction over an area within a 25-mile radius of the City Hall of both cities. The purpose of this Commission is to enable the state's two largest cities to plan and develop a unified system of airports, thereby ending a costly rivalry in airport construction and uniting the metropolitan area in a program of aeronautical development that would be beneficial to the entire state. The Commission controls and manages a system of airports that encircles the entire metropolitan area. The system includes one major air-carrier airport and five general-aviation airports. The growth in based aircraft is indicative of the fact that general aviation has prospered under this operation. In 1951, there were 225 based aircraft; by the end of 1961, the total was 802 based aircraft--an increase of over 200 percent in 10 years. (The rate of increase of active aircraft in the metropolitan area was comparable, so this is an actual growth of activity for the area.) This was accomplished by a public body serving an entire metropolitan area through planning on a regional basis.

Direct technical and financial participation by the FAA is highly desirable in developing regional plans in metropolitan areas. This regional plan should include all aviation--that is, air-carrier, general-aviation, and military flight activity. The plan may involve more than one community and should be projected into the future to examine long-range needs for multiple air-carrier and general-aviation airports. The plan should define activities for each airport and demonstrate that the airport meets the needs of the population as to access and service; it should also provide for airspace requirements within the area and between airports. Most important is that a program for initiating the plan should be included. Such a program will include financing, ownership, and legislation to accomplish the objectives.

IV. LAYOUTS OF GENERAL-AVIATION AIRPORTS

This limited discussion of the layout of general-aviation airports covers the following selected factors of FAA airport design that have been re-evaluated:

1. Runway length and corrections,
2. Effect of crosswinds,
3. Effect of noise,
4. Annual capacity of general-aviation airports,
5. Runway, terminal, and service facilities.

A. <u>RUNWAY LENGTH AND CORRECTIONS</u>

"Airport Design" (reference 7) specifies takeoff and landing runway-length requirements for various general-aviation aircraft. These distances vary with aircraft type, weight, and temperature. The range of the specified runway lengths at 100°F is from 1435 to 3990 feet for aircraft weighing from 740 to 9700 pounds on takeoff.

It is difficult to obtain good performance data on general-aviation aircraft. The numbers and types of these aircraft are too great. The FAA "Statistical Study of U. S. Civil Aircraft" (reference 8) lists 81 models with 76 or more active aircraft (76 is 0.1 percent of the total active general-aviation aircraft). Therefore, the two basic runway lengths that are suggested for planning purposes are:

1. <u>Light-Aircraft Runway (2200 feet)</u>.--To accommodate most single-engine aircraft and many light, twin-engine aircraft. For use in training and local flying.
2. <u>General-Aviation Runway (3500 feet)</u>.--To accommodate all general-aviation propeller aircraft to 12,500 pounds with IFR capability.

Figure 4-1 shows corrections for both runways for airport elevation, temperature, and runway grade. These runway lengths should be suggested as a general guide to the designer and should not prevent him from selecting a different runway length for specific aircraft.

Runway widths and clearances, clear zones, and approach clearance requirements are contained in the FAA manual "Airport Design" (reference 7).

The choice of length is based on examination of runway-length requirements for the landing or takeoff distances for many aircraft. The lengths include a safety factor that varies with individual aircraft but is generally 20 percent or more.

Tables 4-I and 4-II and Figures 4-2 and 4-3 show the specific aircraft types and the maximum takeoff and landing distances for each aircraft under the minimal safe conditions of:

1. Takeoff over a 50-foot obstacle,
2. Landing over a 50-foot obstacle.

Figures 4-2 and 4-3 show that most single-engine aircraft require a length of about 1500 feet or less; twin-engine aircraft require about 2500 feet or less.

Figures 4-4 and 4-5 show a comparison of the takeoff and landing requirements for a sample of general-aviation aircraft under varying temperature conditions.

Figure 4-6 shows the takeoff distance required as a function of airport elevation above sea level for various aircraft types. Most aircraft in the general-aviation class below 12,500 pounds require more takeoff distance than is available with a 7-percent correction factor (suggested by FAA in reference 13). For the light-aircraft runway, a 16-percent runway-length correction for each 1000-foot increase of runway elevation to an elevation of 3000 feet and a 20 percent correction thereafter to 6000 feet has been included in Figure 4-1. Above 6000 feet, correction should be made by the performance of individual aircraft.

Figure 4-7 indicates the variation of climb-out angle with airport elevation for a sample of modern aircraft. Reference 14 gives additional data. The current criteria (reference 13) of 20 to 1 reduces the approach-zone safety margin at the higher elevations. To maintain a more adequate clearance, a graduated approach zone criteria is suggested in Figure 4-1.

Figure 4-8 shows the variation of accelerate-stop distance with gross aircraft weight for various aircraft types. Most general-aviation aircraft are not required to comply with this criterion, but it assists in evaluating runway length.

Figure 4-9 shows the percent of total general aviation operations as a function of the runway length required from a sample taken at Washington National Airport. The runway length required is the ground distance that it takes an aircraft to clear a 50-foot-high obstacle on a standard day. Note that about 40 percent of the total aircraft and 80 percent of the general-aviation aircraft could be accommodated on a 3500-foot runway.

TABLE 4-I

LANDING OR TAKEOFF DISTANCE (WHICHEVER IS GREATER) OVER 50-FOOT OBSTACLE--
CURRENTLY ACTIVE AIRCRAFT*

Aircraft Number	Aircraft Type	Distance (feet)	Gross Weight (pounds)	Number of Engines	Number of Active Aircraft (reference 8)
1	Aero Design 500	1350	6000	2	87
2	Aero Design 520	1300†	6000†	2	104
3	Aero Design 500A	1200	6250	2	123
4	Aero Design 560	1452	6500	2	199
5	Aero Design 680E	1700	7500	2	272
6	Aero Design 680F	2165	8000	2	
7	Aeronca 65	1000†	2000	1	379
8	Aeronca 7 Series	1100	1450	1	3400
9	Aeronca 11	1100†	2050	1	1028
10	Aeronca 15AC	1100†	2050	1	220
11	Beech AT11	2400†	8750	2	96
12	Beech C18S	2500	9700	2	174
13	Beech D-G18S	2616/1850**	9700	2	1059
14	Beech J35	1450	2900	1	303
15	Beech 35	1300	3125	1	>4500
16	Beech 33	1282	2900	1	164
17	Beech 45-A45	1200	2950	1	172
18	Beech D50E	1840	6300	2	
19	Beech G50	1800	7150	2	558
20	Beech J50	2640/1845**	7300	2	

TABLE 4-I (cont)

Aircraft Number	Aircraft Type	Distance (feet)	Gross Weight (pounds)	Number of Engines	Number of Active Aircraft (reference 8)
21	Beech 95	2210/1595**	4100	2	389
22	Bellanca 1413	586	1300	1	340
23	Callair A-3	500	1500	1	133
24	Callair A-5	1050	2150	1	
25	Cessna T-50	1300†	5700	2	130
26	Cessna 120	1250	1450	1	1058
27	Cessna 140	1250	1450	1	2912
28	Cessna 150	1205	1500	1	844
29	Cessna 172	1370	2200	1	3899
30	Cessna 170	1350	2200	1	3205
31	Cessna 175	1340	2350	1	1490
32	Cessna 180	1080	2650	1	2141
33	Cessna 182	1080	2650	1	3233
34	Cessna 190	1200	3350	1	113
35	Cessna 195	1300	3350	1	570
36	Cessna 210	1130	2900	1	457
37	Cessna 310C	1610	4830	2	1040
38	Cessna 310F	1395	4830	2	
39	Champion DX'ER	750	1650	1	139
40	Commonwealth Rearwin	900†	1460	1	91
41	Downer 14-19	800	2600	1	172

TABLE 4-I (cont)

Aircraft Number	Aircraft Type	Distance (feet)	Gross Weight (pounds)	Number of Engines	Number of Active Aircraft (reference 8)
42	Downer RC-3	800	2150	1	223
43	Douglas DC3 Super 3	2510	25,200	2	
44	Ercoupe	600	1400	1	>100
45	Fairchild 24W Series	1100	2562	1	87
46	Fairchild M62	1200	2741	1	197
47	Forney 415 Series	800	1400	1	2202
48	Forney E Aircoupe	1050	1400	1	79
49	Forney F-1 Aircoupe	1050	1400	1	99
50	Jobmaster Howard DGA 15	1300	4350	1	86
51	Luscombe 8 Series	990	1410	1	2463
52	Mooney Mark 20 Series	850	2450	1	464
53	McClish-Funk B Series	600	1350	1	96
54	Naval Aircraft N3N3	1200†	2900†	1	138
55	Navion Series	1055	3150	1	1213
56	North American AT-6	1308	5111	1	334
57	Piper J3 Series	800	1220	1	3547
58	Piper J4	800	1300†	1	177
59	Piper J5	800	1400	1	273
60	Piper PA 11	800	1400	1	460
61	Piper PA 12	900	1750	1	1510
62	Piper PA 14	950	1220	1	118

TABLE 4-I (cont)

Aircraft Number	Aircraft Type	Distance (feet)	Gross Weight (pounds)	Number of Engines	Number of Active Aircraft (reference 8)
63	Piper PA 15	800	1150	1	186
64	Piper PA 16	900'	1650	1	498
65	Piper PA 17	-	-	1	118
66	Piper PA 18	960	1500	1	290
67	Piper PA 18	500	1500	1	2444
68	Piper PA 20	1000	1650	1	566
69	Piper PA 22	1100	2000	1	5489
70	Piper PA 23	1265	3800	2	1712
71	Piper PA 24	1200	2800	1	1973
72	Piper PA 25	1200	2800	1	273
73	Ryan-Navion ST3KR	800	2850	1	120
74	Stearman	800	2717	1	1926
75	Stinson L-5	900	2400	1	
76	Stinson V77	850	2400	1	415
77	Stinson 215HP Series	825	2400	1	
78	Taylorcraft B Series (40/225)	900	1200	1	
79	Taylorcraft B Series (55/140)	925	1200	1	2171
80	Taylorcraft D65 Series	900	1200	1	
81	Universal GC-1 Series (Temca Swift)	1000	1710	1	659
82	Universal 108 Series (Stinson)	900	2400	1	2260

* This information was obtained from references 9, 10, 11, and 12 in addition to manufacturers performance data.

** Second number is short-field configuration.

' Estimated.

TABLE 4-II

LANDING OR TAKEOFF DISTANCE (WHICHEVER IS GREATER) OVER 50-FOOT OBSTACLE--
MISCELLANEOUS AIRCRAFT*

Aircraft Number	Aircraft Type	Distance (feet)	Gross Weight (pounds)	Number of Engines
1	Aerocar 11A	1100	2200	1
2	Aero Design 720	1757	7500	2
3	Beech 55	2515/1745**	4880	2
4	Beech 65	1980/1690**	7700	2
5	Beech Super-V Conv.	1550	3400	2
6	Bellanca 260	1050	2800	1
7	Cessna 185	1510	3200	1
8	Coleton 880	1422	1709	1
9	Coleton 885	950	2200	1
10	Coleton Super Rallye	1298	1708	1
11	Conrad 9800D	2300	9800	2
12	Convair 240	4500	42,500	2
13	Culver V	980	1600	1
14	DeHavilland DH2	1015	8000	1
15	DeHavilland DH3	1015	8000	1
16	DeHavilland 600	2270	8950	2
17	DeHavilland 800	2270	8950	2
18	Dornier DO27-Q3	750	3740	1
19	Dornier DO27-Q4	935	4080	1
20	Dornier DO28	902	5137	2

TABLE 4-II (cont)

Aircraft Number	Aircraft Type	Distance (feet)	Gross Weight (pounds)	Number of Engines
21	Fachiro PT711	1470	2135	1
22	Fletcher FU24	1000	3500	1
23	Grumman Gulfstream	3000	35,100	2
24	Helio H395	500	3000	1
25	Helio H395A	475	3000	1
26	Howard 500	2950	35,000	2
27	Lake LA4	1500	2400	1
28	Lanier 443	300	3550	1
29	Leasiar 102	750	3550	1
30	Leasiar 104	640	3550	1
31	Lockheed 60	1040	3532	1
32	Lockheed Jetstar	4750	40,069	4
33	Marksman A	3790	35,000	2
34	Marksman B	3125	35,000	2
35	Marksman Marketeer	3970	35,000	2
36	Meteor II	1620	3800	2
37	Meyers 200A	1550	3000	1
38	Meyers 200B	900	3000	1
39	Miles M100	2640	7300	1
40	Mooney M21	1000	2450	1
41	Nibbio F14	1080	2550	1

TABLE 4-II (cont)

Aircraft Number	Aircraft Type	Distance (feet)	Gross Weight (pounds)	Number of Engines
42	Piaggio L-1	1380	6000	2
43	Piaggio L-2	1525	6614	2
44	Piaggio P1494	1700	4009	1
45	Piaggio P166	1570	8115	2
46	Piper PA23-250	1365	4800	2
47	Riviera FN333	925	3150	1
48	Safir 910	2050/1400**	2650	1
49	Tempo II	4950	35,000	2
50	Trecker 166	1540	8100	2

* This information was obtained from references 9, 10, 11, and 12 in addition to manufacturers performance data.

** Second number is short-field configuration.

A runway gradient affects the takeoff distance required to clear a 50-foot obstacle in two ways: (1) the takeoff acceleration during the ground run is reduced by the weight component that opposes the thrust, and (2) the gradient increases the absolute altitude at which a 50-foot clearance is attained. For example, with a 1-percent gradient at a point 1000 feet from lift off, the runway is 10 feet higher and 50 feet of clearance is 60 feet of incremental altitude.

The effect of runway gradient on the ground run depends on the ratio of excess thrust to gross weight. The percentage increase in ground run for high-powered aircraft would be less for a given gradient than for moderately powered aircraft. For light aircraft, the sea-level acceleration at lift off is about 3 ft/sec^2 (reference 15). A 1-percent gradient is equivalent to an opposing acceleration of 0.32 ft/sec^2. Since the percentage increase in ground-run distance is about equal to the percentage change in acceleration at takeoff speed, a sea-level ground-run correction of 10 percent for 1-percent gradient seems adequate to compensate for the ground-run portion of the takeoff.

The ground-run correction is small when compared to the increase in distance required to clear a 50-foot obstacle when the gradient holds constant along the entire takeoff path. This distance depends on the initial climb angle and therefore is sensitive to altitude and temperature changes. At sea level, assuming a minimum aircraft performance of 8 percent climb slope, the air distance would increase by 14 percent per 1-percent runway gradient. At 6000 feet, a 4-percent climb slope (minimum performance) gives a 33-percent increase in air distance per 1-percent runway gradient.

A reasonable overall correction for both ground run and climb to 50 feet that covers the sea level case and appears to adequately compensate for temperature and altitude effects is to apply a 15-percent correction to the runway lengths derived from Figure 4-1 for each 1-percent runway gradient.

B. EFFECT OF CROSSWINDS

The present crosswind criteria are:

1. "Runways should be oriented so the airport has a usability factor as large as is practicable but in no case less than 95 percent of the time, with a crosswind component not greater than 15 miles per hour" (reference 7).

2. Where preferential runway-use programs have been established for aircraft over 12,500 pounds, runway direction is chosen to avoid exceeding a 15-knot velocity at 80 degrees from centerline (reference 16).

On the basis of our discussions with general-aviation pilots, operators, and officials, higher crosswind components might be acceptable. However, we do not suggest any change in criteria but do suggest greater application of economic justification for a second runway.

FAA Regulations of the Administrator, Part 550 (reference 17) specifies the first crosswind criteria but indicates that need for a second runway must also be based on operational experience and economic justification. If a crosswind runway is considered, its economic justification can be assessed by the technique of evaluating runway performance against facility construction, amortization, and maintenance costs. The use of this technique is demonstrated in Section VII for the analysis of an additional runway at Lambert-St. Louis airport.

The number of runway directions that can be justified depends on wind conditions, topography, and volume of traffic. With a single runway direction, operations of aircraft will be restricted some of the time because of the velocity of the crosswind.

Runway realignment or the addition of a second runway can be justified by the direct effect of wind if the percentage of increase in the total cost of the facility is equal to the percentage by which the utility of the airport can be increased. A secondary effect would be the loss in growth of activity because of the lack of reliability. Many of the local operations that would have been handled at the time the airport is not usable because of crosswind may be rescheduled and not cause any loss. It is believed that the net loss for a general-aviation airport does not exceed the percentage of time the airport is not usable.

On this basis, the need for a secondary runway or a more favorable alignment may be analyzed either by comparing the gain in income to the additional cost, or by comparing the gain in percentage of usability to the percentage of increased development cost.

C. EFFECT OF NOISE IN LANDING AND TAKEOFF OPERATIONS

At airports having ample runway length and clear zones, general-aviation aircraft of 12,500 pounds or less present no appreciable noise problem to the public. Since such aircraft comprise the bulk of the general-aviation population, no major noise problem exists. However, zoning of nearby property to guide residential development will help to keep this from becoming a major problem. The larger type of general-aviation aircraft, such as the Gulfstream and Jetstar, are a minority, and these aircraft normally require air-carrier airport facilities. It would seem that noise will not be a serious general-aviation airport problem in the foreseeable future.

D. ANNUAL CAPACITY OF GENERAL-AVIATION AIRPORTS

Reference 18 shows that the precise capacity of an airport must be determined for that individual airport because the capacity varies with the following factors:

1. Runway configuration,
2. Weather,
3. Types of aircraft,
4. Airspace considerations,
5. Arrival-to-departure ratio.

FAA has criteria based on the growth of traffic at an airport to guide designers in determining when additional runway facilities are needed. For example, reference 6 states:

"Paragraph 550.23, Policy

"(d) 1. The following will be used in determining need for new airports--annual air carrier operations in excess of 30,000 will be used as a guide to determine whether a separate airport is needed for general aviation.

"(f) 2. When the volume of air carrier and military traffic is approaching 50,000 operations and involves mixing various types of aircraft with different speed characteristics, consideration will be given to the development of a general aviation airport under this special fund.

"Paragraph 550.24, Programming Standards

"(f) 6. On the basis of traffic volume, an airport with 75,000 or more annual aircraft movements of all types, not qualifying for a second runway on the basis of winds, will be eligible for a second runway on the basis of traffic volume, provided that the layout and orientation of the two runways will permit both to be used to expedite traffic."

Based on our extensive work with airport capacity, a review has been made of the annual capacity of a general-aviation airport. The following discussion will show that the typical annual capacities are considerably higher than the FAA criteria. Because of the time involved in planning and constructing facilities, the level of aircraft operations at which planning begins must be below capacity. However, the level can be raised substantially over that in current FAA use.

The following typical annual-capacity figures have been determined and can be used as a planning guide for general-aviation airports.

Primary-Runway Length (feet)	Annual Capacity (operations per year)
2200	190,000
3500	200,000
5000	165,000 to 190,000

These figures are for an airport with a single runway with mixed operations (landings and takeoffs) and with good runway turnoffs. They can also apply to intersecting runway layouts where only a single runway is usually used. Each airport will have a specific capacity that may vary from these figures. Thus, although the typical figures are suitable for general planning purposes, specific action for a specific airport should be based on a careful determination of capacity for that airport.

It should be noted that these annual capacities are far less than those achieved at airports such as Washington National (312,992 in fiscal year 1961) and LaGuardia (261,320 in fiscal year 1960). The actual hourly runway capacity is lower at these busy air-carrier airports than at the general-aviation airport. The high annual total results because the peak-hour capacity is 7 or 8 percent of the total daily capacity at air-carrier airports whereas it is as high as 15 and 20 percent at the general-aviation airports (reference 18).

The annual capacity is the sum of the VFR and IFR capacities of an airport computed by the method shown in Table 4-III. This table was derived using the following factors:

1. It has been found helpful in operational and capacity analysis of airports to group air-

TABLE 4-III

CALCULATION OF ANNUAL CAPACITY OF GENERAL-AVIATION AIRPORTS

Case	Aircraft Population (percent) Type C	Type D	Type E	Percent of Type E Touch-and-Go Operations	Capacity (operations per hour) Without Touch-and-Go Operations	With Touch-and-Go Operations	Non-VFR Demand (operations per hour) VFR/IFR Weather	IFR Weather
1	30	30	40	30	80	103	41	10
2	10	30	60	30	87	120	46	7
3	0	40	60	40	89	129	46	7
4	0	10	90	40	97	150	47	0

Case 1:

$$\frac{50 \text{ days} \times 103 \text{ operations/hour}}{15 \text{ percent daily operations per peak hour}} + \frac{225 \text{ days} \times 103 \text{ operations/hour}}{20 \text{ percent daily operations per peak hour}} + \frac{54 \text{ days} \times 41 \text{ operations/hour}}{20 \text{ percent daily operations per peak hours}}$$

$$+ \frac{24 \text{ days} \times 10 \text{ operations/hour}}{20 \text{ percent daily operations per peak hour}} = 162{,}500$$

$$\approx 165{,}000 \text{ operations per year}$$

Case 2:

$$\frac{50 \times 120}{0.15} + \frac{225 \times 120}{0.20} + \frac{54 \times 46}{0.20} + \frac{24 \times 7}{0.20} = 188{,}240$$

$$\approx 190{,}000 \text{ operations per year}$$

TABLE 4-III (cont)

Case 3:

$$\frac{50 \times 129}{0.15} + \frac{225 \times 129}{0.20} + \frac{54 \times 46}{0.20} + \frac{24 \times 7}{0.20} = 201{,}240$$

$$\approx 200{,}000 \text{ operations per year}$$

Case 4:

$$\frac{50 \times 150}{0.20} + \frac{225 \times 150}{0.24} + \frac{54 \times 47}{0.24} = 188{,}850$$

$$\approx 190{,}000 \text{ operations per year}$$

craft by their performance on the airport. The following designations are used:

Type A	Large turbojet aircraft,
Type B	Small jet (such as 727) and all large propeller aircraft above 36,000 pounds,
Type C	Large twin-engine aircraft between 8000 and 36,000 pounds,
Type D	Small twin-engine and high-performance single-engine aircraft (such as Bonanza),
Type E	Small single-engine aircraft.

2. Previous studies have shown the marked effect of aircraft population and runway layout on capacity. For the development of annual-capacity figures, we had to select typical situations. The turnoff layouts used are optimum--high speed exits on the 5000-foot runway and well-placed right-angle turnoffs on the shorter runways. A few examples of the operating levels achieved during 1961 at general-aviation airports are shown in Table 4-IV (reference 19).

3. Fifty VFR peak days are used as an indication of the number of days of the year when high volumes of traffic will be experienced.

4. The remaining 315 days are divided between (a) average days with good weather, (b) days with VFR weather but when ceilings and visibility are below 1500 feet and 5 miles, respectively, called VFR/IFR weather, and (c) days when IFR weather prevails. We have used 225 days of average VFR days, and an additional 54 days when weather will be above IFR but not good enough to permit extensive itinerant flight with VFR procedures. We have used 36 days of IFR weather as typical of that time when ceiling and visibility is below 1000 feet and 3 miles, with only 24 days as flyable IFR; the remaining 12 days are below the minimum ceiling and visibility (snow, etc.).

TABLE 4-III (cont)

<u>Case 3</u>:

$$\frac{50 \times 129}{0.15} + \frac{225 \times 129}{0.20} + \frac{54 \times 46}{0.20} + \frac{24 \times 7}{0.20} = 201{,}240$$

$$\approx 200{,}000 \text{ operations per year}$$

<u>Case 4</u>:

$$\frac{50 \times 150}{0.20} + \frac{225 \times 150}{0.24} + \frac{54 \times 47}{0.24} = 188{,}850$$

$$\approx 190{,}000 \text{ operations per year}$$

TABLE 4-IV

ANNUAL OPERATIONS AT SELECTED GENERAL-AVIATION AIRPORTS

Airport	General Aviation Itinerant	General Aviation Local	Other Aviation	Total
Phoenix, Arizona	142,868	78,198	*	221,066
Hawthorne, California	**	**	0	140,000**
Santa Monica, California	115,034	95,275	7,708	218,017
Hayward, California	73,153	104,178	4,609	181,940
Fulton County, Georgia	36,344	105,758	14,579	156,681
Bowman, Kentucky	62,955	112,438	3,632	179,025
Teterboro, New Jersey	69,029	127,286	1,658	197,973
Zahns, New York	75,000	145,000	0	220,000**

Note: All airports have either a single- or intersecting-runway configuration.

* General aviation operates almost exclusively on single north runway; thus, only general aviation is included.

** Estimate.

5. VFR capacity for a general-aviation airport requires some special treatment because of the extensive occurrence of touch-and-go operations, for the two operations are equal to one arrival in computing capacity. Thus, if this factor is not taken into account, the number of operations actually recorded by a tower will be unusually high compared with a capacity forecast. In our projections, we included a reasonable percentage of touch-and-go operations as part of the total air-traffic analysis. Thus, the annual-capacity figure of Table 4-III is directly comparable with the air-traffic activity reports compiled by controllers in the control towers. Table 4-V gives some background for determining the proportion of touch-and-go operations.

6. From the extensive analysis of airport capacity performed under Contract FAA/BRD-136 (reference 18) and work performed by AIL for the Port of New York Authority (reference 1) and for City of Chicago Aviation Department (reference 20), we have concluded that because of the cost of delay, queue length, and our observations of delay, the practical capacity of a runway configuration at an air-carrier airport is reached at a 4-minute average delay. However, we believe that this average delay should be reduced in determining general aviation airport capacity because it is unlikely that, where scheduled operations are not involved, the user of the airport will continue to accept a 4-minute delay but will, in general, try to find other facilities. Figure 4-10 shows the variation in capacity for 2-, 3-, and 4-minute average delays. We believe that, when a 2-minute delay figure is reached, the practical capacity of the airport will also be reached. The practical capacity can be exceeded but only with excessive delay. Because the 2-minute delay is obtained at a relatively low utilization (from a mathematical standpoint), it can be applied directly to the predicted peak hour of traffic. Therefore, with a 2-minute average delay during the peak hour, about 77 percent of all aircraft will have some delay, 48 percent will be delayed 1-1/2 minutes or more, about 26 percent will be delayed 3 minutes or more, and 1 percent will be delayed 9 minutes or more (reference 1).

TABLE 4-V

AMOUNT OF TOUCH-AND-GO TRAFFIC DURING PEAK-CAPACITY HOURS AT TWO GENERAL-AVIATION AIRPORTS FOR 1960

		Teterboro Airport (percent)	Westchester Airport (percent)
Population of Aircraft	Type B	0	5
	Type C	10	30
	Type D	25	25
	Type E	65	40
Local		86.3	71.1
Itinerant		13.7	28.9
Arrivals		17.2	23.6
Departures		17.2	23.6
Touch-and-Go		65.6	52.8

Analysis of the peak hours for capacity is important. For comparison, at Teterboro for fiscal year 1961, annual operations show total local operations for general aviation to be only 64.1 percent of total operations. At Westchester for fiscal year 1961, local operations were 31 percent of total operations.

7. An important consideration in computing annual capacity is the relation between the peak hour and the remainder of the day. Reference 18 includes a distribution of traffic for general-aviation airports. We have re-examined this information using field data as it became available. We have examined existing FAA publications (including "Terminal Area Traffic Relationships," reference 21, released during 1961) and particularly the busy hour and peak-day analyses for general-aviation airports. However, they do not show good correlation with the capacity analyses when projected to an annual basis.

The daily distribution of traffic has been examined for several general-aviation airports. Figure 4-11 shows the percent of daily traffic handled in each hour at ten general-aviation airports in the Washington, D. C. area. It is interesting to note that the average peak-hour percent for the busier airports is 16.6, whereas the average peak-hour percent for the more lightly loaded (and smaller) airports is 22.3. It should also be noted that the percent given is somewhat high because, if the survey would have covered all daylight hours, there would have been additional total operations.

Figures 4-12 through 4-15 show three days of operations at Pal Waukee Airport, Illinois; Fullerton Airport, California; Flying Cloud Airport, Minnesota; and Crystal Airport, Minnesota. For these busy airports, the peak-hour percentages are low. In Figure 4-16, the peak-hour percentages have been plotted for all of these observations. The peak-hour percentages tend to decrease as the daily operation rate increases. From this analysis we have concluded that the peak-hour on an average peak day (that we find may occur about 50 times per year) should be 15 percent (except for the airport with 2200-foot runways, where a factor of 20 percent is used). We have further concluded that the other days of the year (that are more lightly loaded) should have a peak-hour capacity of 20 percent (24 percent at airports with 2200-foot runways).

8. To determine IFR capacity, the amount of IFR demand must be considered. We have attempted to find some relationship between the demand during IFR weather and during VFR weather. Figure 4-17 shows airports that are classified as air-carrier airports because air-carrier stops are scheduled there; however, more than half of their traffic is general-aviation traffic.

Generally, it is true that during IFR conditions air-carrier operations will continue as in VFR. Using this basis, we have computed the weighted ratio of itinerant general aviation traffic operating during IFR to get an indication of what percent of general aviation traffic will operate in IFR if proper facilities are available. It should be noted that this would be applied only to those general-aviation airports that are capable of having good IFR facilities and certainly would include only those with runways of 3500 feet or more. From this analysis, it is concluded that about 22 percent of the general-aviation itinerant traffic made instrument approaches in IFR weather during 1961 at the airports analyzed. A further indication that this is reasonable is that about 25 percent of active general aviation aircraft are equipped with localizer receivers, 55 percent with VHF Navigation equipment, 7 percent with glide slope receivers, and 19 percent of general aviation pilots are instrument rated (reference 22). Thus, the equipment and pilot capability is adequate to result in 22 percent making instrument approaches.

Forecasts available (Project Beacon) do not include general-aviation instrument approaches. The percent making instrument approaches will increase in the future but the rate of increase is unknown. On the other hand, the IFR demand at small airports is generally less than at the airports analyzed. Therefore, we have used 20 percent of itinerant traffic as a reasonable estimate of this value for the near future years.

9. The demand during VFR/IFR weather would drop considerably as most itinerant VFR cross-country traffic would not operate, and local flying would decrease. We have arbitrarily assumed that this net effect would be to reduce demand for Type C and D aircraft to 50 percent and for Type E aircraft to 30 percent, as a step between VFR and IFR.

10. The IFR capacity is computed only if IFR approach procedures are established on a basis where they are reasonably useful to general aviation. We have assumed IFR capacity for the 3500- and 5000-foot runways (none for the 2200-foot runway).

E. RUNWAY, TERMINAL, AND SERVICE FACILITIES

The layout for each airport should be based on a careful analysis of the type and volume of activities to be accommodated, the services to be offered, weather conditions, topography of the site, highway access, air-traffic patterns, and land-use in the surrounding area.

Except for special circumstances resulting from inadequate wind coverage and unusual topography, general-aviation airports should have only a single runway or two parallel runways. Parallel runways should be used to attain high capacities. In metropolitan areas, each general-aviation airport should be planned for an ultimate capacity of 150 to 500 based aircraft (discussed further in Chapter 8). For smaller communities, one airport should be planned for the total potential traffic and, where air-carrier service is available, the same airport will normally accommodate general aviation and air-carrier flights.

From data published in references 19 and 23, the normal activity level for general-aviation aircraft is about 700 annual operations per based aircraft. There are, of course, wide variations from this level, particularly at the airports in a metropolitan area where the various airports handle different segments of the total traffic. Airports serving principally itinerant flights or training activities will have substantially more traffic per based aircraft. With an activity level of about 700 operations per aircraft per year, when an airport grows past 300 active based aircraft, a parallel-runway layout probably will be required to provide adequate capacity.

Five layouts are shown as guides for general-aviation planning in metropolitan areas. The smallest facility (Figure 4-18) has a single paved runway (50 feet wide and 2200 feet long) for light aircraft and training activities. Where the potential activity is low and other conditions are favorable, no pavement is required and a smaller building area will permit the use of an area of about 30 acres, or one-half of that shown. It should be noted that 150 or more aircraft can be accommodated on an area only twice the size of that required for only ten based aircraft.

Other layouts show a single runway 75 feet by 3500 feet (Figure 4-19), one 75 feet by 3500 feet plus a crosswind runway 50 feet by 2200 feet (Figure 4-20), two parallel runways 75 feet by 3500 feet (Figure 4-21), and a layout for local air-

carrier service and general aviation with two intersecting runways, one 100 feet by 5000 feet and one 75 feet by 4000 feet (Figure 4-22).

The large variation in the number and size of aircraft based on or using a general-aviation airport requires that the type and extent of service facilities be determined by the activities to be accommodated. At very small communities, only an aircraft parking area can be justified. For airports with greater activity, individual plane hangars, fueling facilities, service hangars, sales and public waiting space, restaurant, weather services, and pilot briefing facilities should be added.

The focal point for activities on a general-aviation airport is the service area for pilots of itinerant aircraft and includes fueling facilities, weather service, ground transportation, and food services. These should be near the normal exits of the runway that will be near the midpoint of the runway. The aircraft service hangar should be nearby, as well as itinerant-aircraft parking or tie-down areas. The storage areas for aircraft based at the airport should be beyond the itinerant storage and service area. If there is a prevailing wind, these areas should be located between the service area and the takeoff point. Automobile parking should be provided adjacent to each aircraft servicing or storage area. Widely separated facilities are inconvenient and tend to reduce patronage of the services offered.

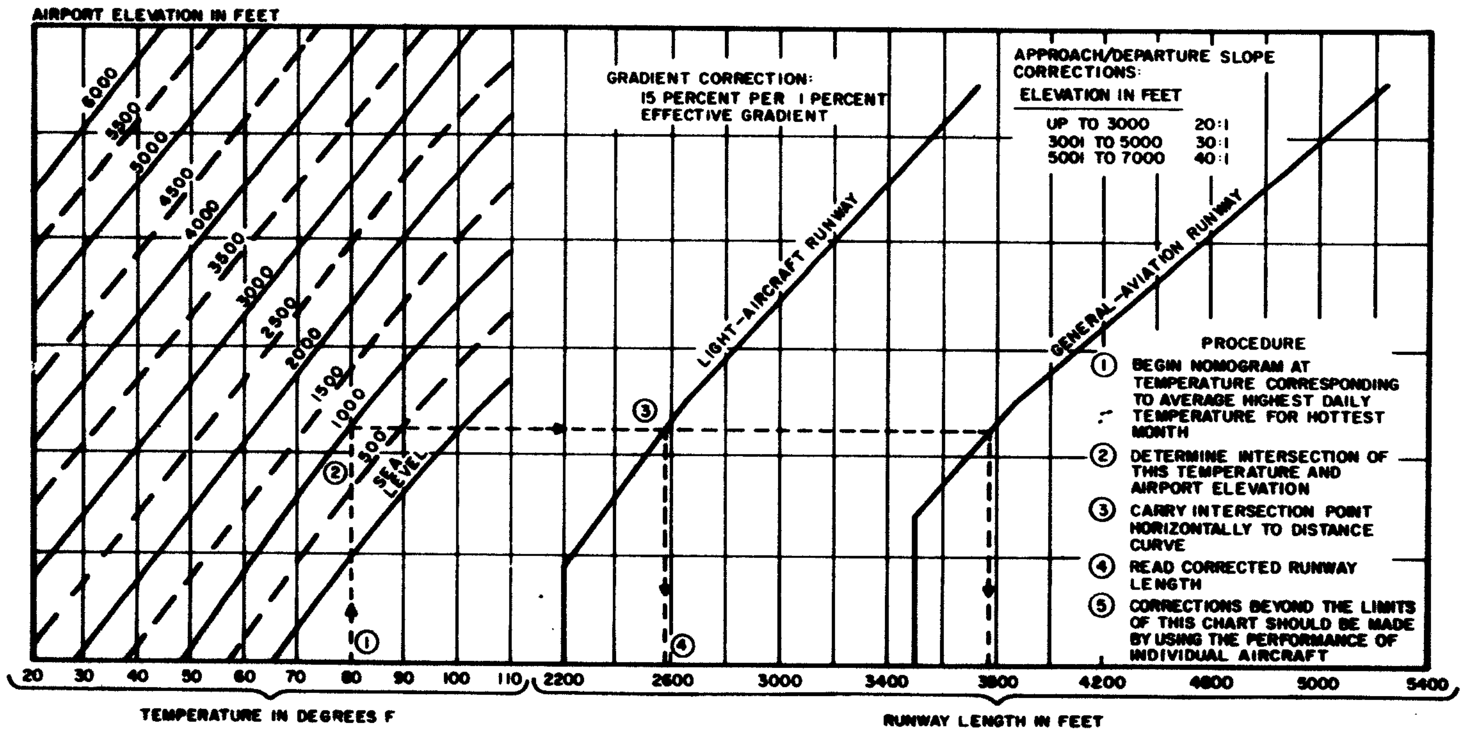


FIGURE 4-1. CORRECTION FACTORS FOR RUNWAYS AT GENERAL-AVIATION AIRPORTS

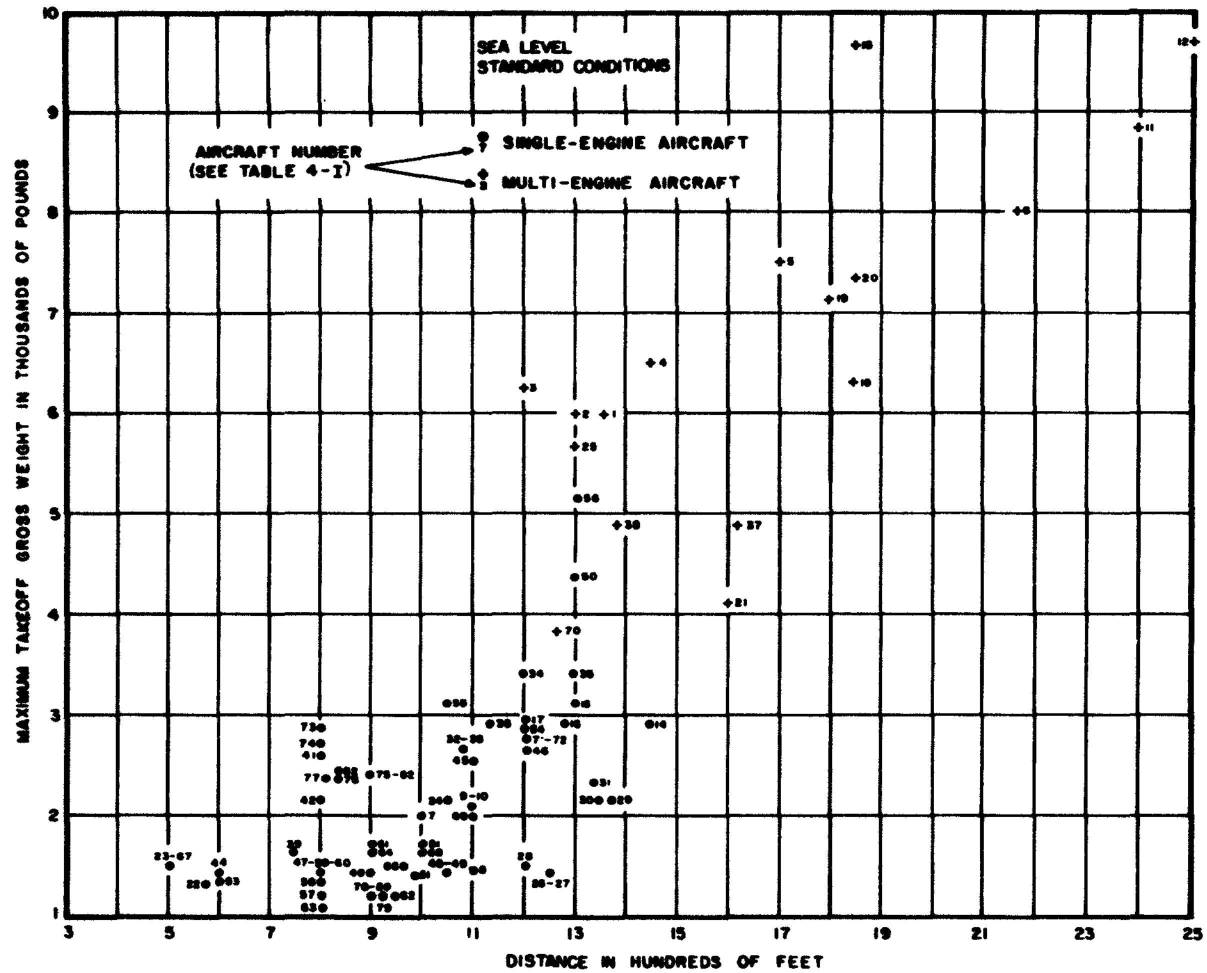


FIGURE 4-2. TAKEOFF/LANDING DISTANCE REQUIRED FOR CURRENTLY ACTIVE GENERAL-AVIATION AIRCRAFT OVER 50-FOOT OBSTACLE

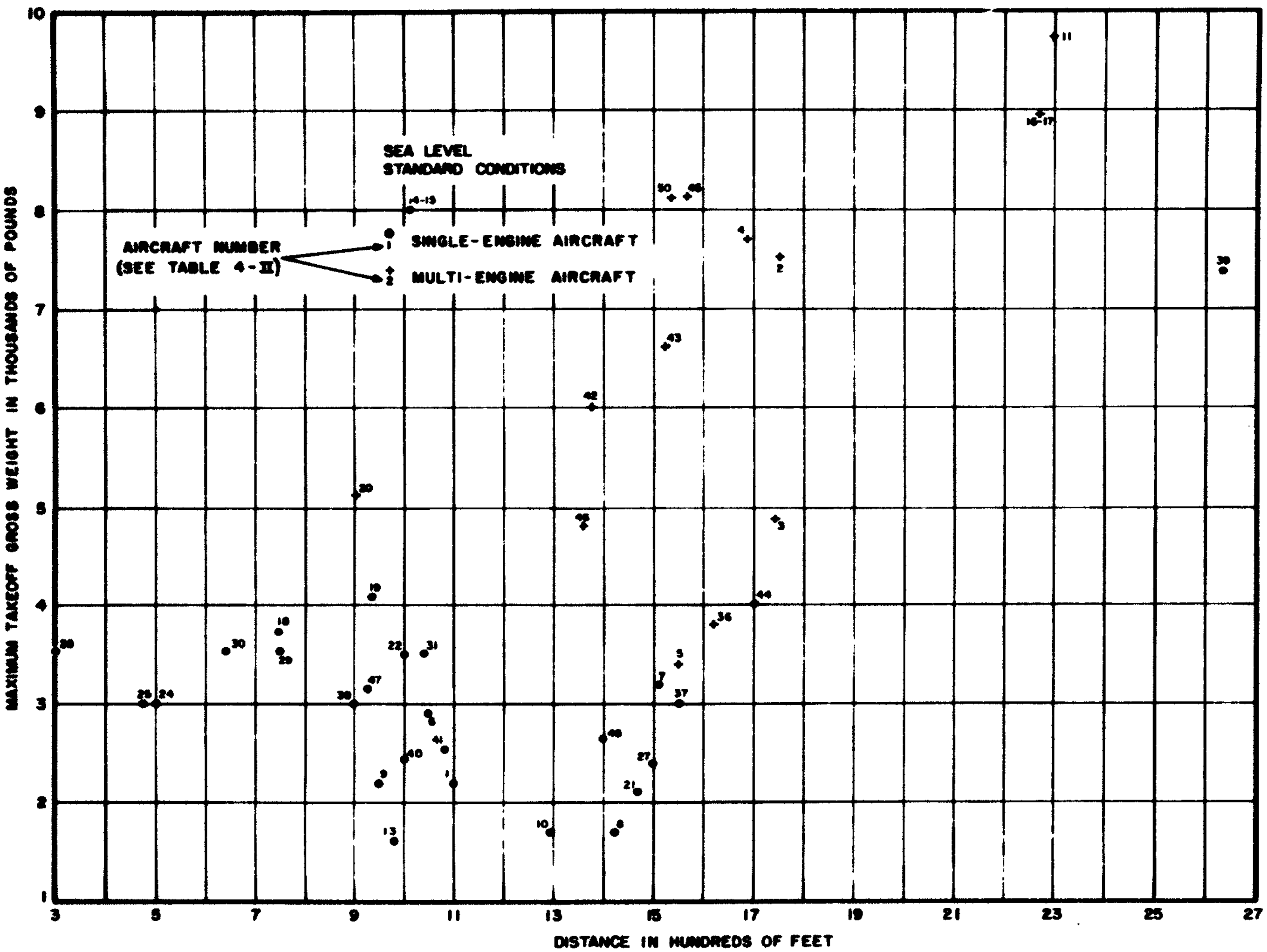


FIGURE 4-3. TAKEOFF/LANDING DISTANCE REQUIRED FOR MISCELLANEOUS GENERAL-AVIATION AIRCRAFT OVER 50-FOOT OBSTACLE

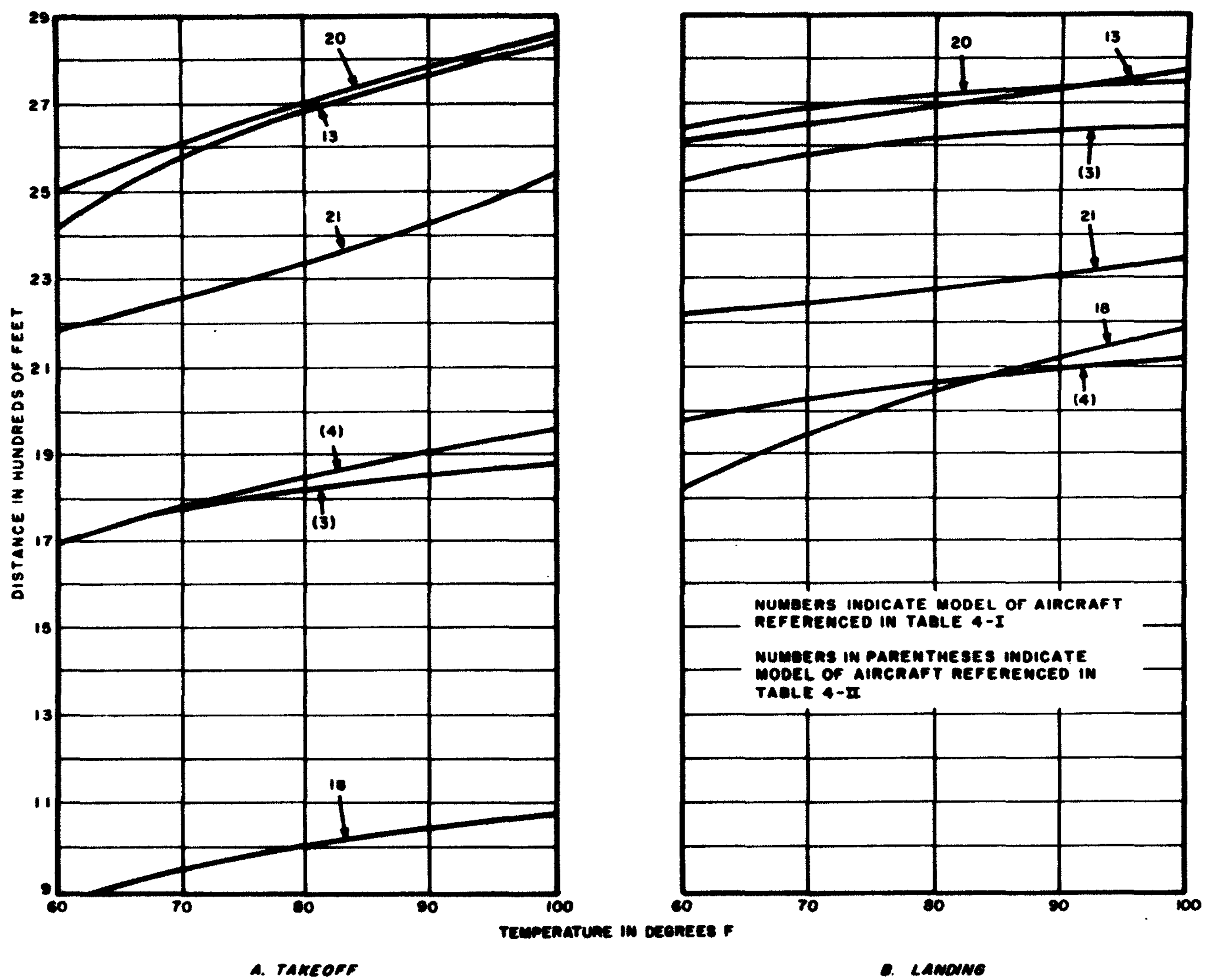


FIGURE 4-4. RELATION BETWEEN DISTANCE AND TEMPERATURE AT SEA LEVEL FOR TAKEOFF AND LANDING OVER 50-FOOT OBSTACLE FOR VARIOUS MODELS OF AIRCRAFT

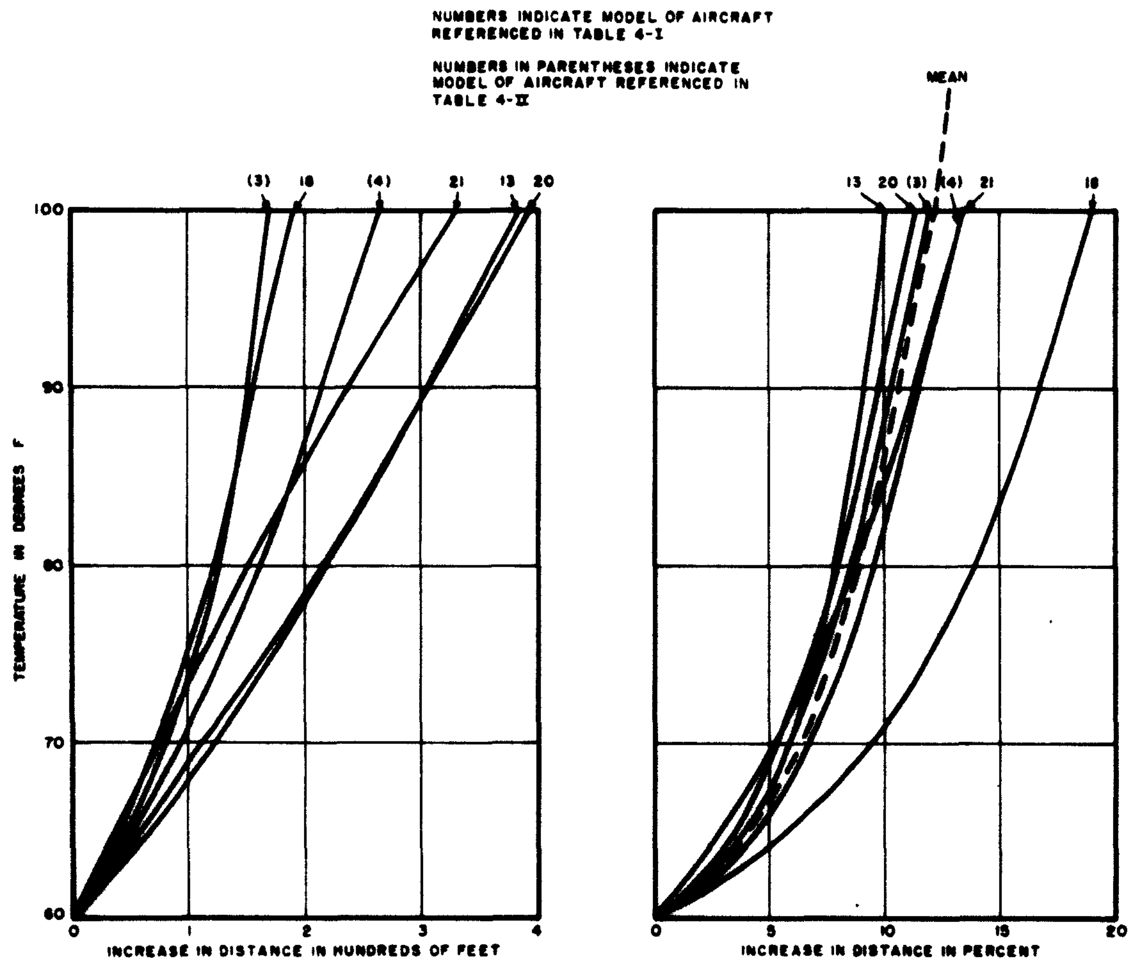


FIGURE 4-5. INCREASE IN DISTANCE DUE TO TEMPERATURE AT SEA LEVEL FOR TAKEOFF OVER 50-FOOT OBSTACLE FOR VARIOUS MODELS OF AIRCRAFT

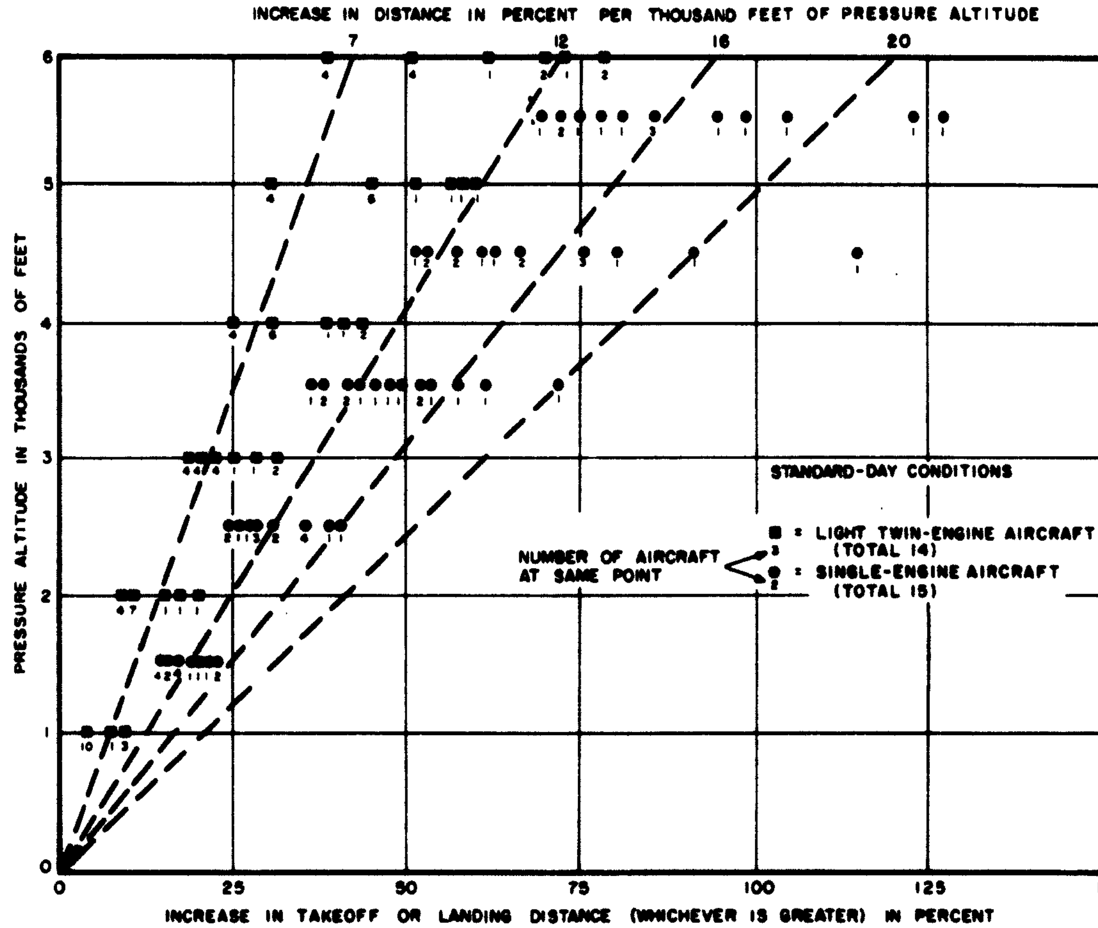


FIGURE 4-6. EFFECT OF AIRPORT ELEVATION ON REQUIRED TAKEOFF DISTANCE OVER 50-FOOT OBSTACLE

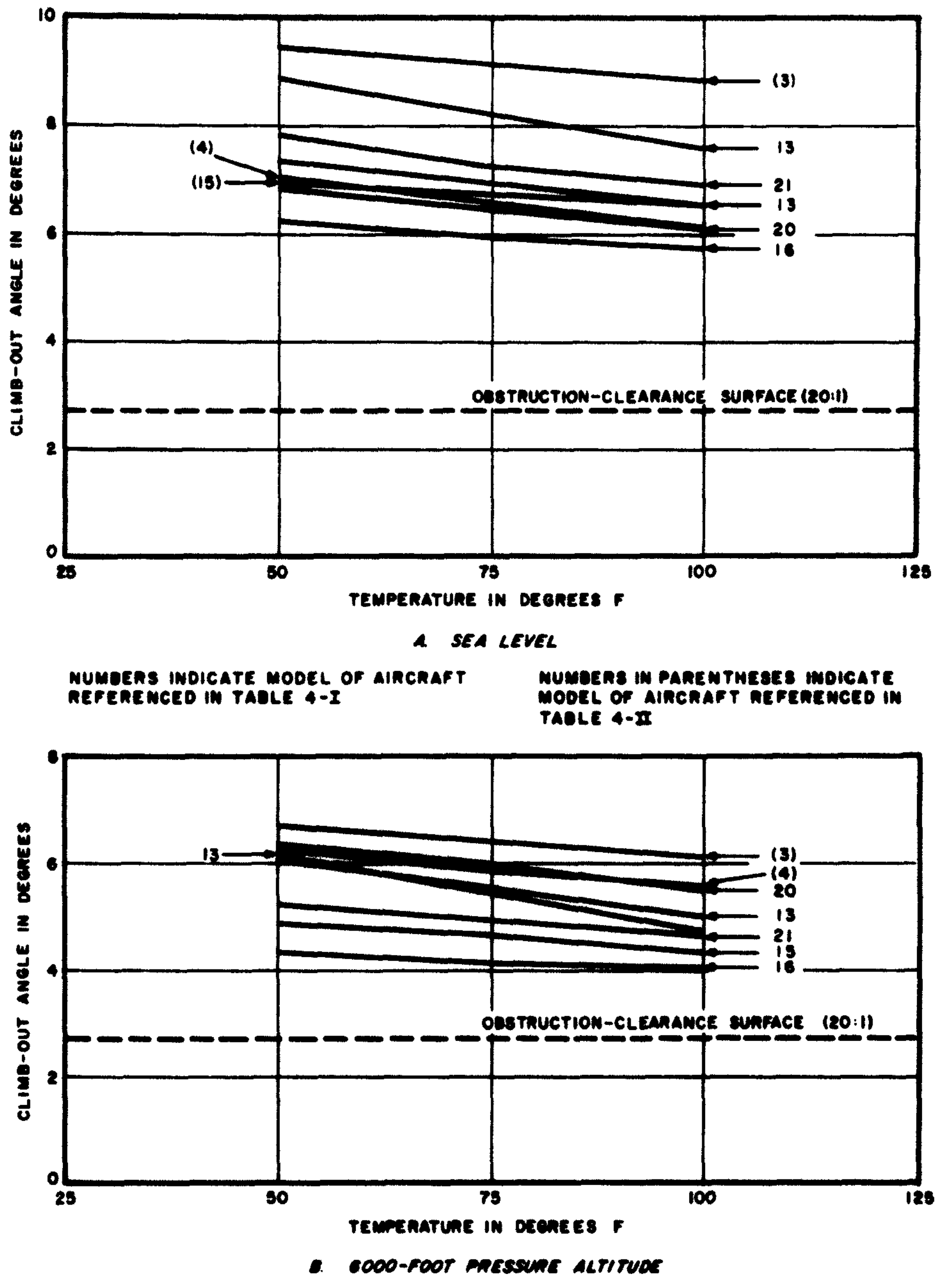


FIGURE 4-7. EFFECT OF AIRPORT ELEVATION ON CLIMB-OUT ANGLE

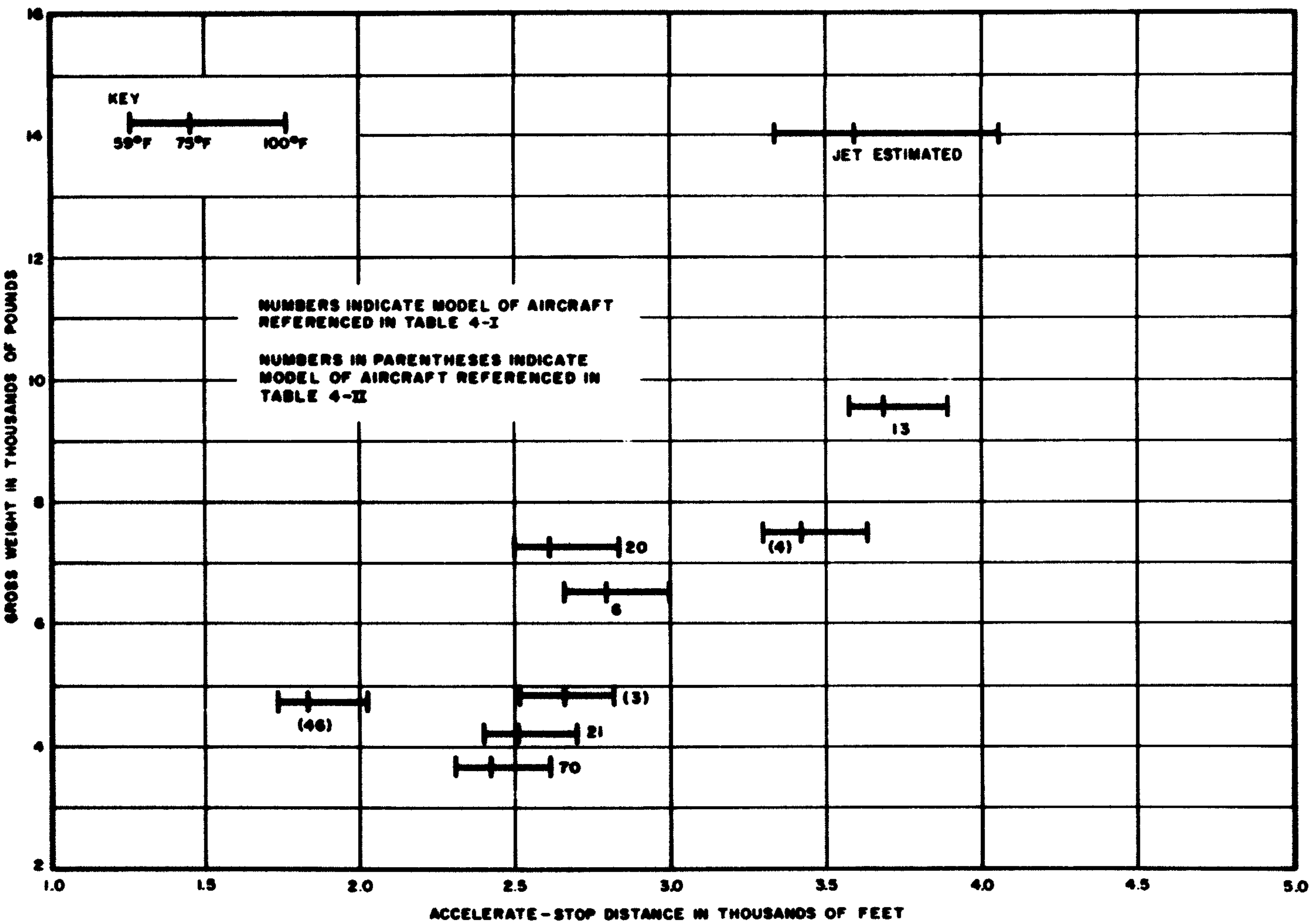


FIGURE 4-8. ACCELERATE-STOP DISTANCE AT SEA LEVEL FOR TYPICAL GENERAL-AVIATION AIRCRAFT

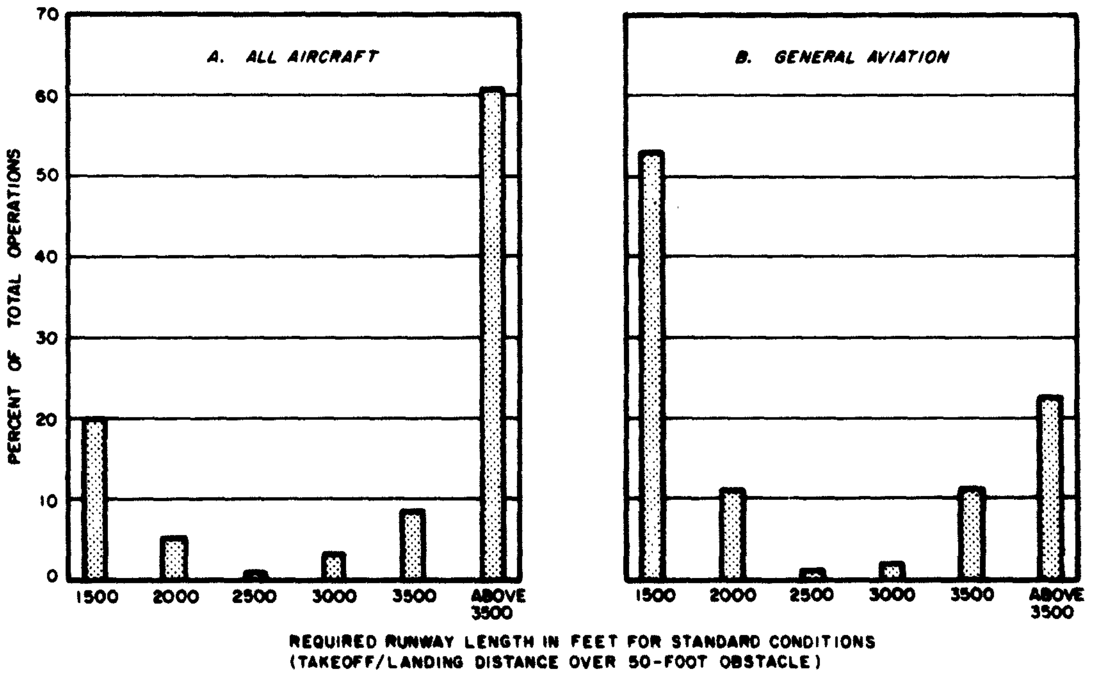


FIGURE 4-9. RUNWAY LENGTH REQUIRED BY AIRCRAFT DURING 2000 SUCCESSIVE OPERATIONS AT WASHINGTON NATIONAL AIRPORT

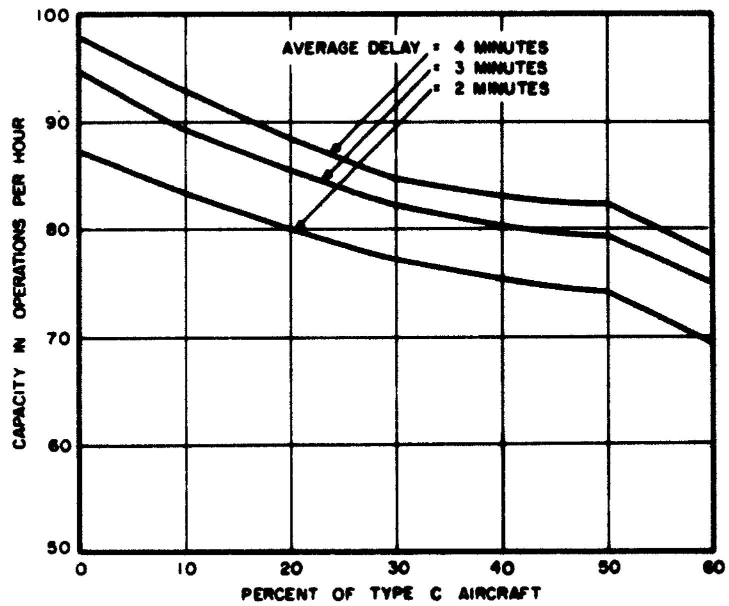


FIGURE 4-10. VARIATION OF PRACTICAL HOURLY RUNWAY CAPACITY WITH AVERAGE DELAY ON RUNWAYS HANDLING ONLY TYPE C, D, AND E AIRCRAFT

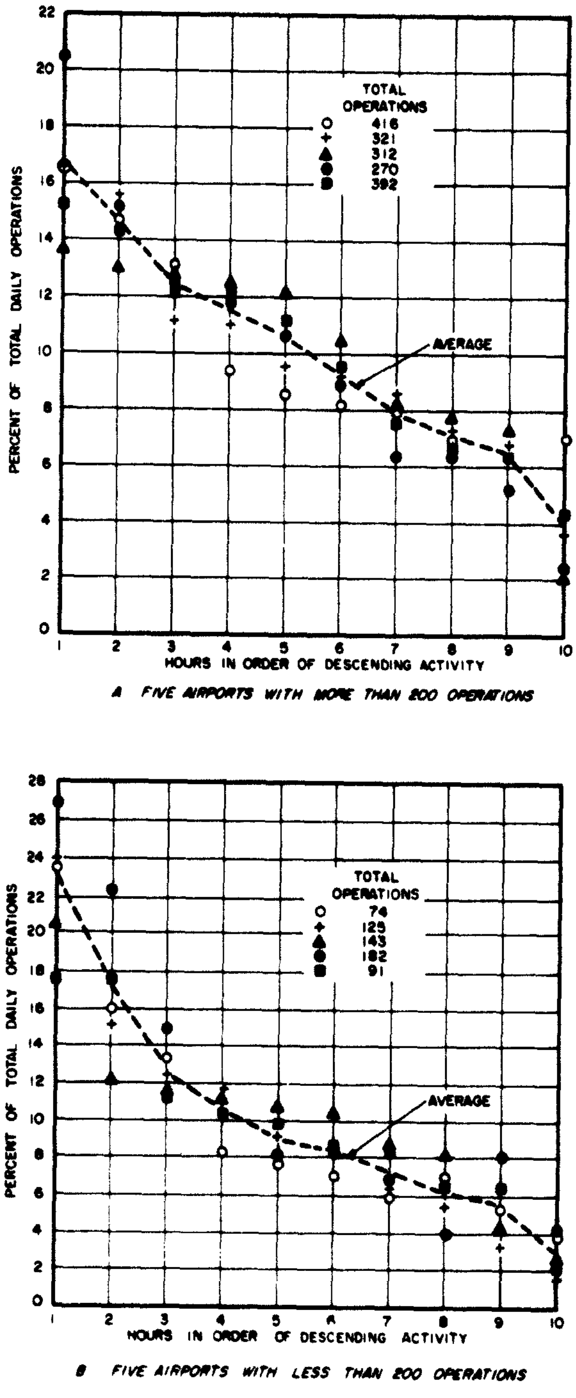


FIGURE 4-11. ANALYSIS OF HOURLY OPERATING RATE AT TEN GENERAL-AVIATION AIRPORTS IN WASHINGTON, D. C. AREA ON 28 AND 29 OCTOBER 1961

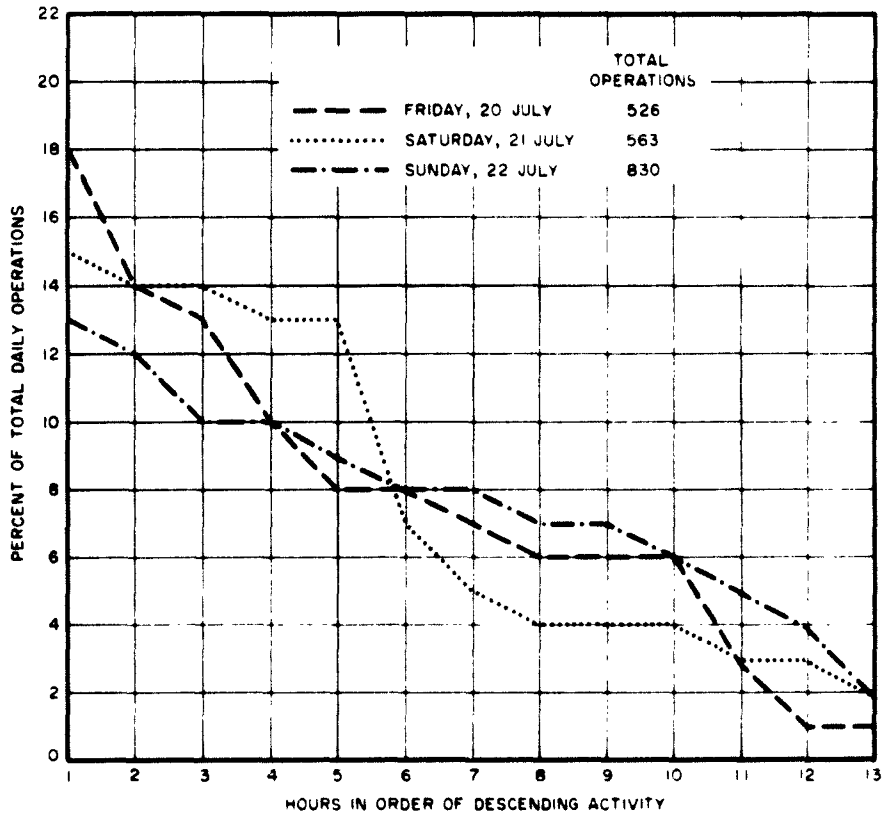


FIGURE 4-12. ANALYSIS OF HOURLY OPERATING RATE AT PAL WAUKEE AIRPORT, ILLINOIS FROM 20 TO 22 JULY 1956

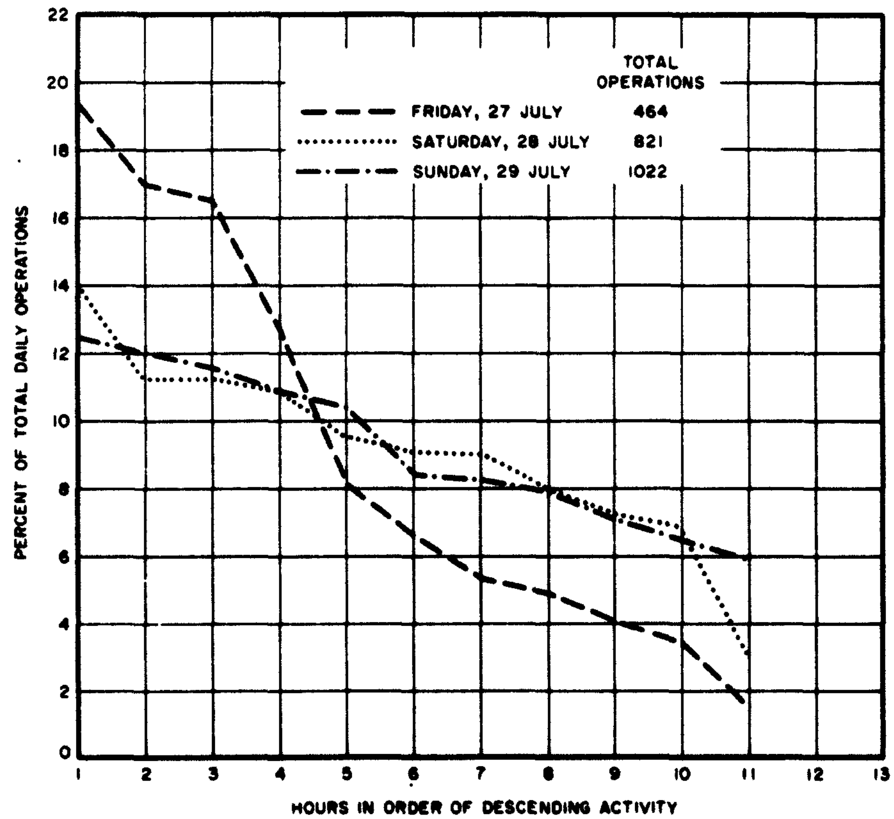


FIGURE 4-13. ANALYSIS OF HOURLY OPERATING RATE AT FULLERTON AIRPORT, CALIFORNIA FROM 27 TO 29 JULY 1956

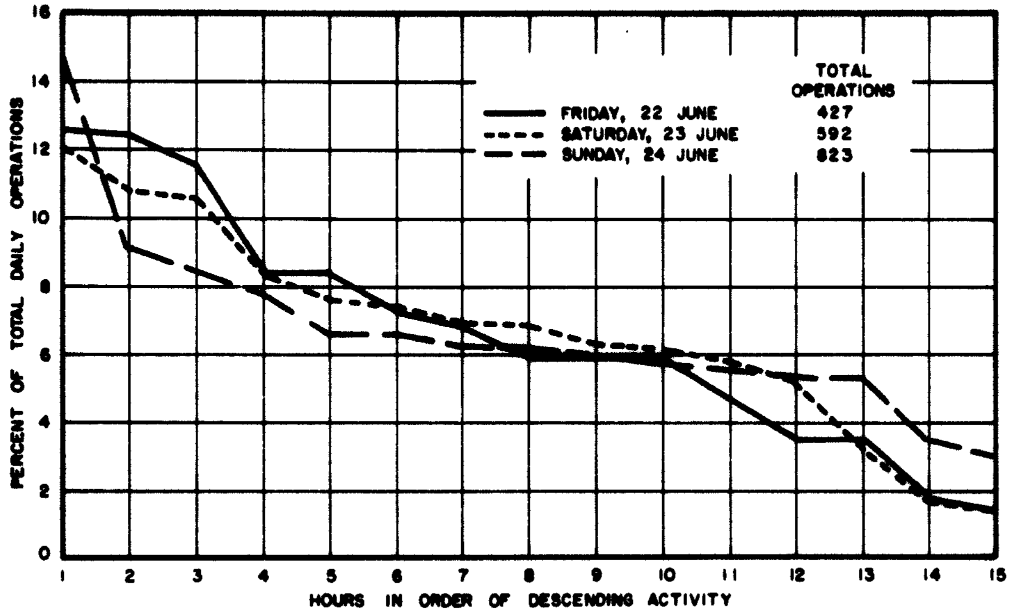


FIGURE 4-14. ANALYSIS OF HOURLY OPERATING RATE AT FLYING CLOUD AIRPORT, MINNESOTA FROM 22 TO 24 JUNE 1962

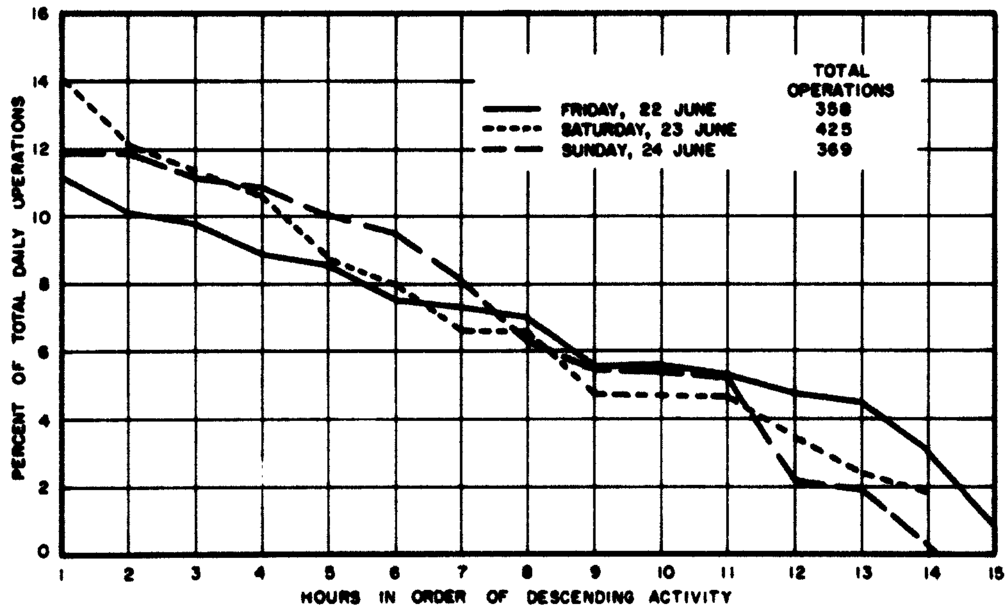


FIGURE 4-15. ANALYSIS OF HOURLY OPERATING RATE AT CRYSTAL AIRPORT, MINNESOTA FROM 22 TO 24 JUNE 1962

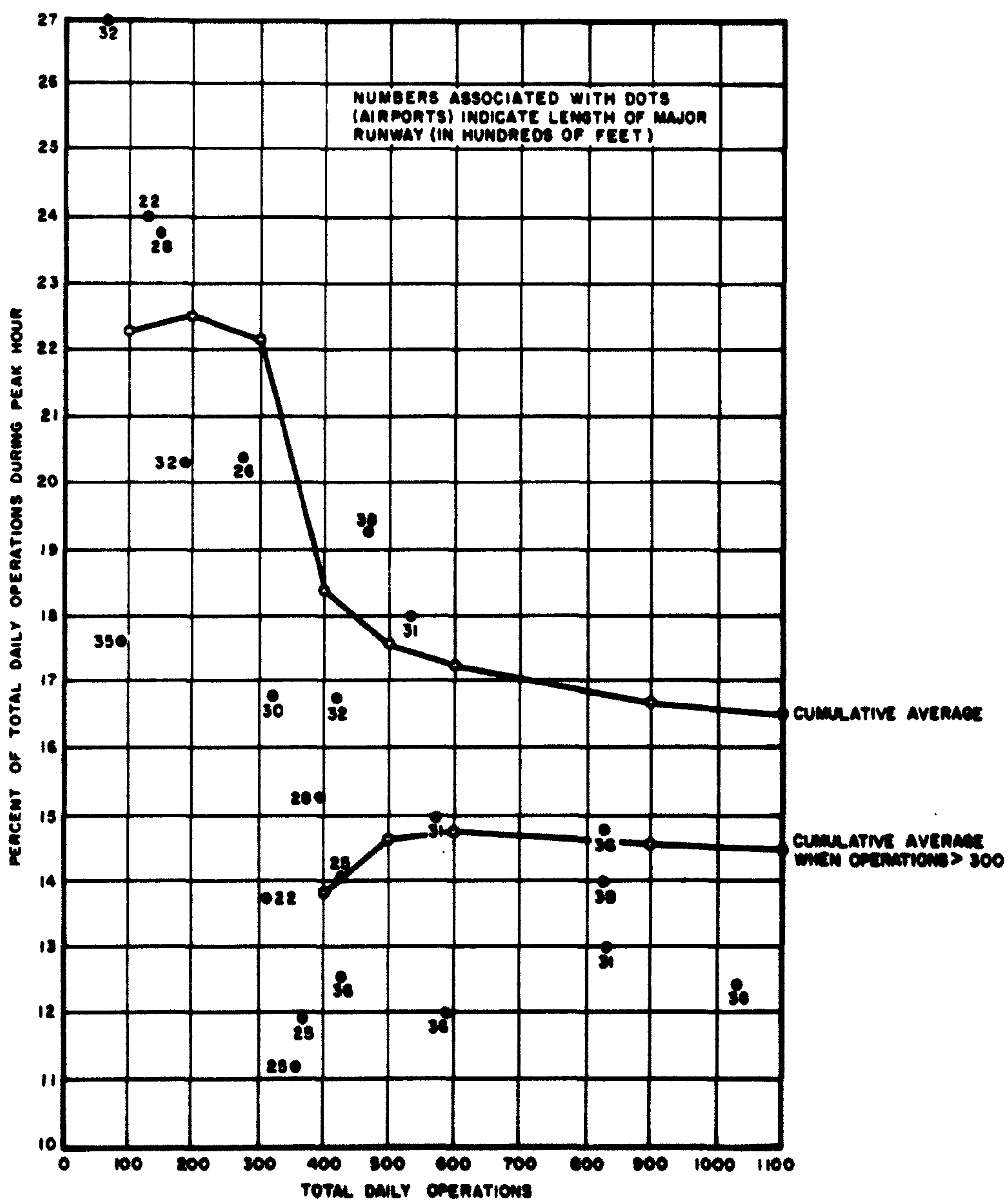
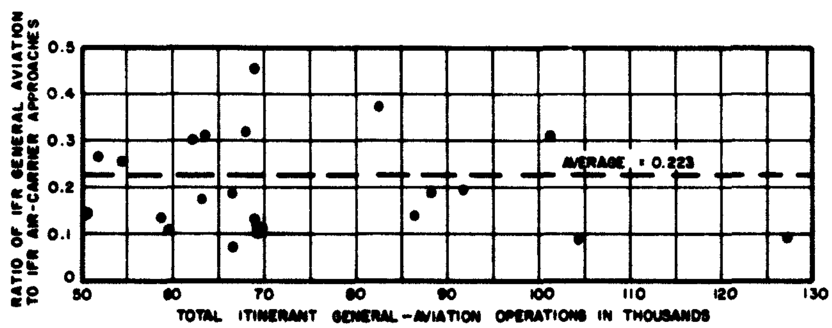


FIGURE 4-16. OPERATIONS OCCURRING DURING PEAK HOUR RELATED TO TOTAL DAILY OPERATIONS



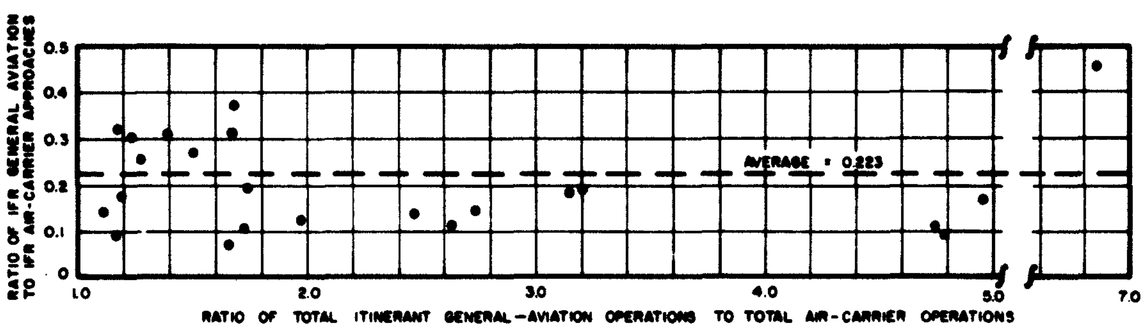


FIGURE 4-17. RELATION OF ITINERANT GENERAL-AVIATION TO AIR-CARRIER INSTRUMENT APPROACHES FOR FISCAL YEAR 1961 AT AIRPORTS WHERE ITINERANT GENERAL-AVIATION OPERATIONS EXCEED BOTH AIR-CARRIER AND 50,000 OPERATIONS PER YEAR

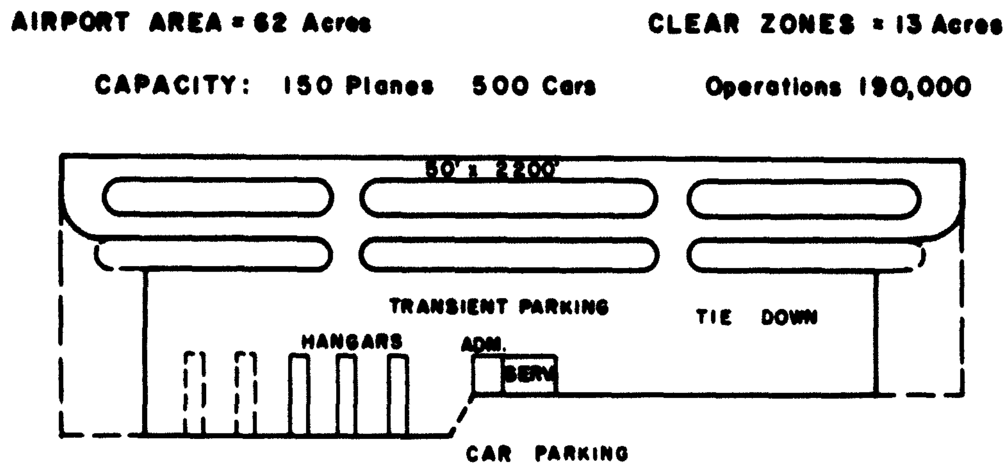


FIGURE 4-18. AIRPORT FOR SINGLE-ENGINE AND TRAINING AIRCRAFT

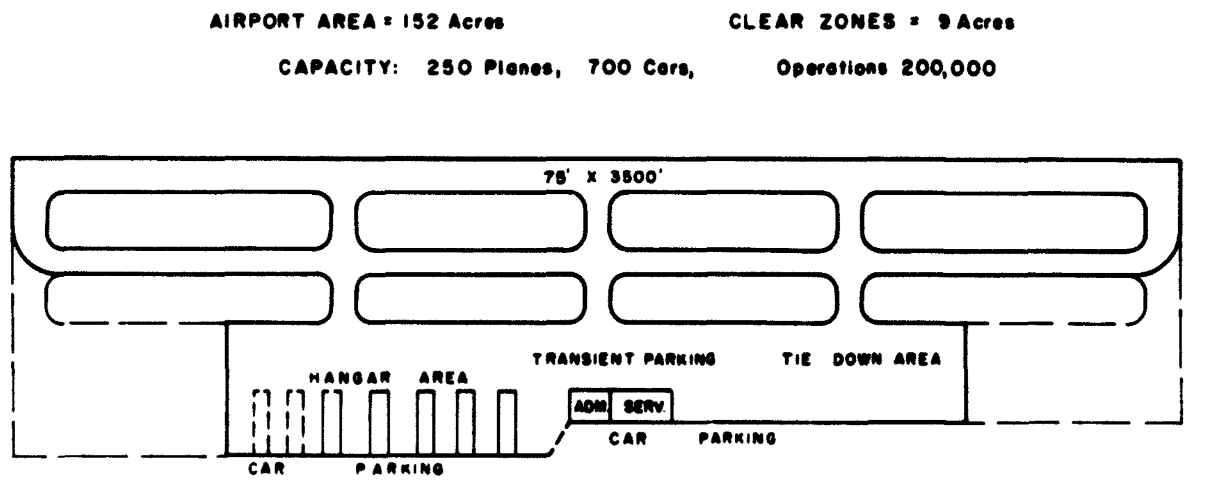


FIGURE 4-19. GENERAL-AVIATION AIRPORT

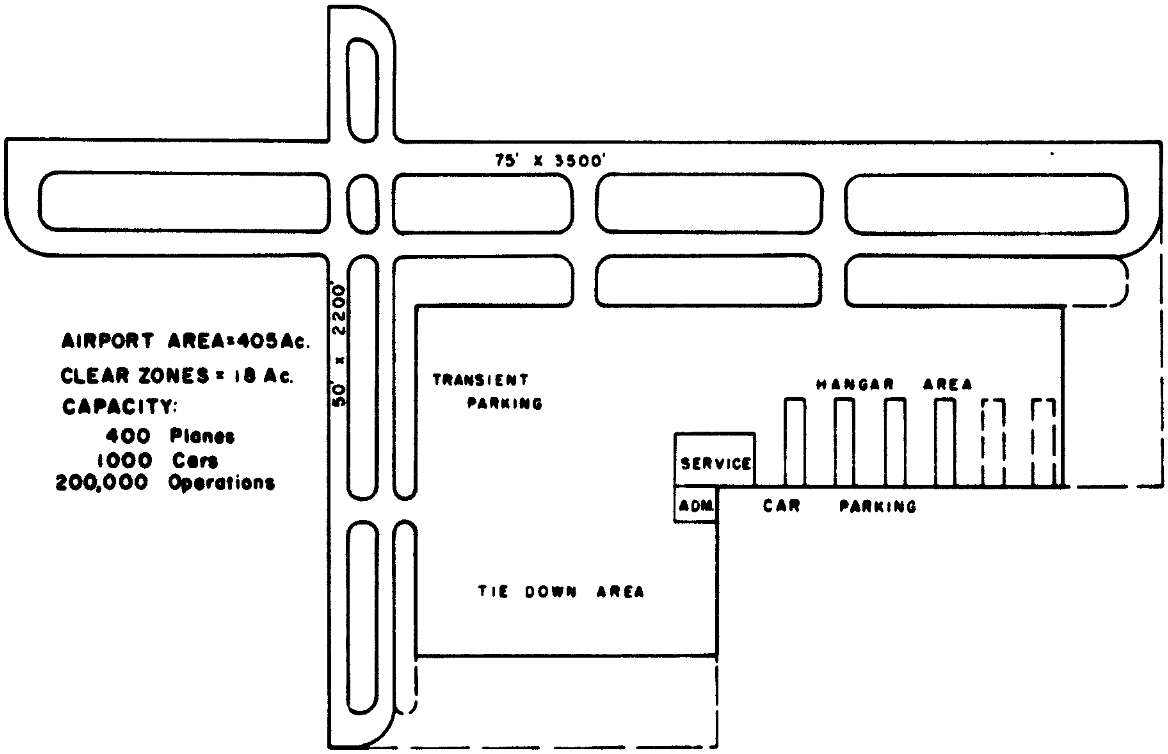


FIGURE 4-20. GENERAL-AVIATION AND TRAINING AIRPORT

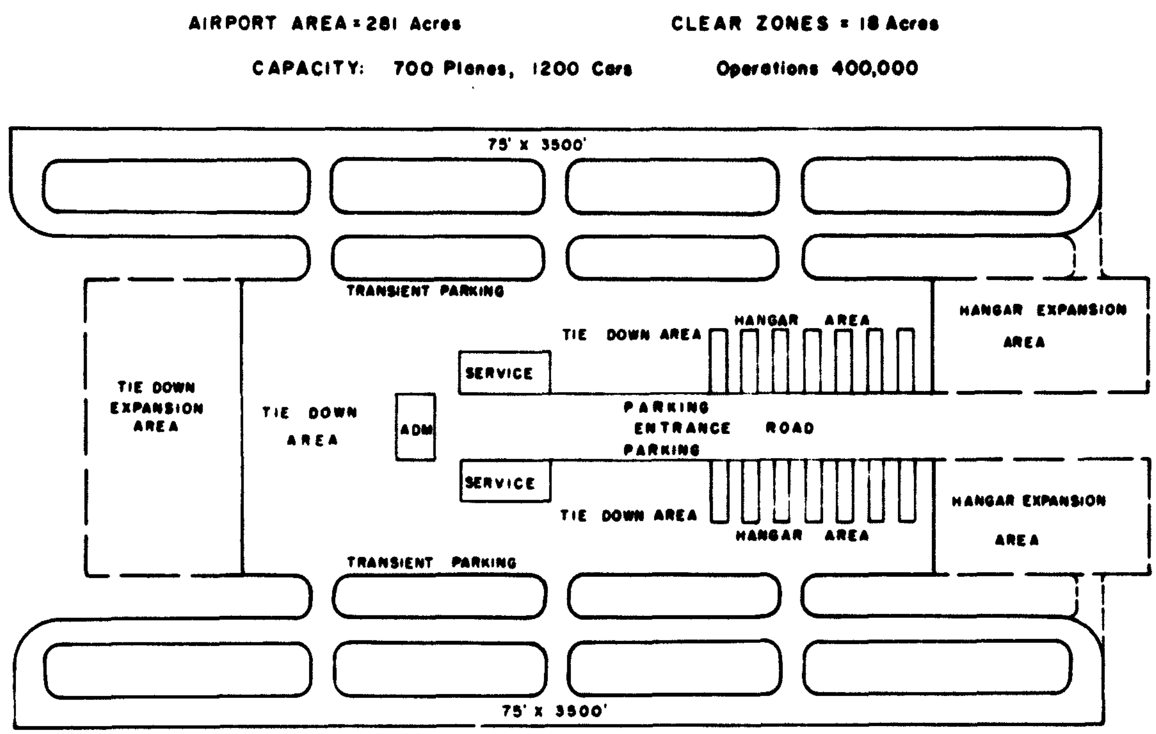


FIGURE 4-21. GENERAL-AVIATION AIRPORT WITH PARALLEL RUNWAYS

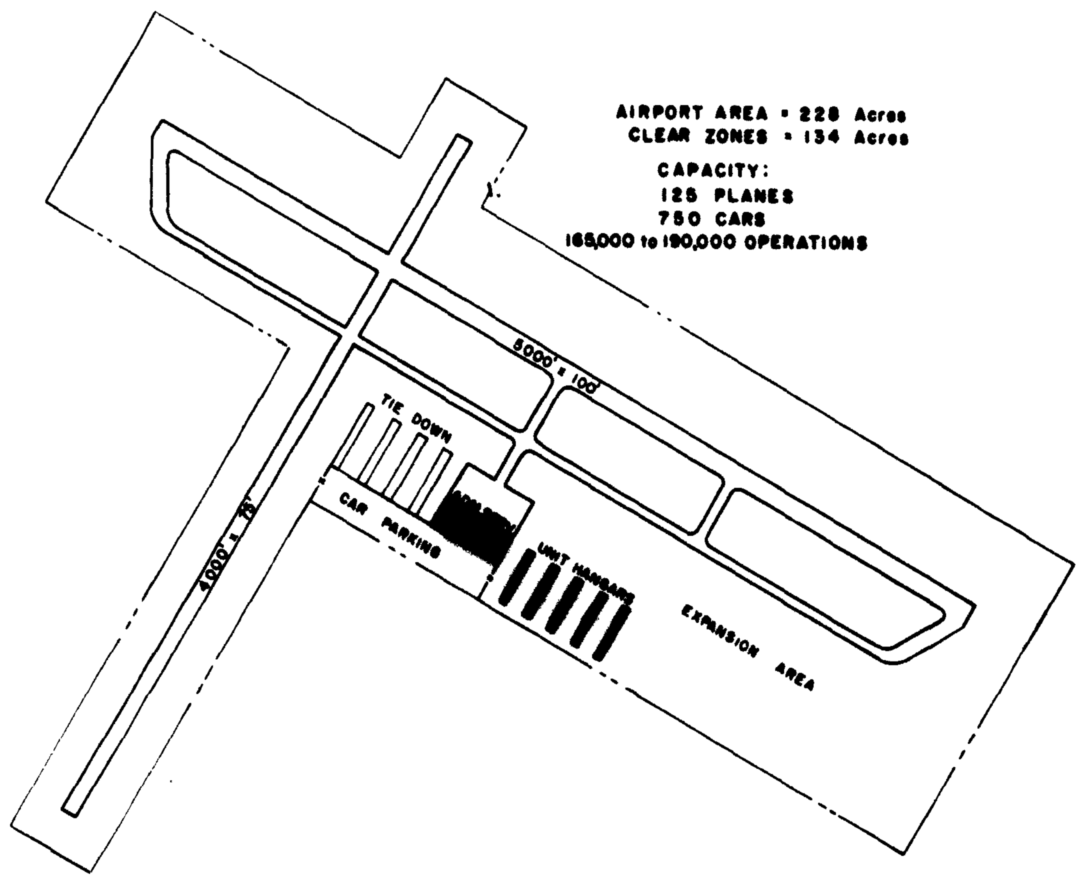


FIGURE 4-22. AIRPORT FOR LOCAL SERVICE AND GENERAL AVIATION

V. GENERAL AVIATION AT AIR-CARRIER AIRPORTS

The Curtis report (reference 24) suggests that, at major airports, short runways parallel to the main runways should be provided to accommodate the lighter aircraft. There has been a growing interest in the concept of providing separate facilities for general aviation at air-carrier airports. Because of this interest, AIL was asked to develop guidance material for use in determining the proper method of handling general aviation landings and takeoffs at air-carrier airports.

The following information will be discussed:

1. Potential layouts for runway configurations and terminal-building areas for general aviation at air-carrier airports.
2. Criteria for selecting the length of a runway when a parallel runway for general aviation is to be constructed at an air-carrier airport.
3. Procedures for determining the practicality of separate facilities for general aviation.

A major recommendation of this study is that decisions regarding the provision of a separate facility in the form of a light-aircraft short runway parallel to a major runway should be based principally on the economic benefit resulting from reduced delay. It should be noted that the economic benefit will result principally to the larger aircraft whose cost of operation is high compared with that of general-aviation aircraft.

Although the principal conclusion bases the decision on economics, an important related factor is the desirable result of separating the light from the heavy aircraft. However, this condition does not provide a major basis for additional facilities because the fact that mixed operations are continually being conducted at our airports today is evidence that this is a safe operation. Further, at many airports, it will be difficult, if not impossible, to provide an additional short runway, thus, all aircraft must continue to operate from common runways.

A. LAYOUTS OF AIR-CARRIER AIRPORTS FOR GENERAL AVIATION

There are seven basic layouts for a set of two parallel runways serving combined air-carrier and general-aviation traffic, as shown in Figure 5-1. A brief discussion of their use is given based on our study and observations.

The first four layouts consist of runways of unequal length, one of air-carrier length for the particular location and a shorter runway to serve the major portion of general aviation. Layout 1 has the terminal area for all aircraft between the runways which would normally be separated by 4000 to 6000 feet. For a location where the total traffic consists of about 35 to 65 percent of general-aviation aircraft, this is the optimum layout. Traffic patterns are well separated and adjacent terminal areas should provide the best service at the lowest cost. Based on current knowledge a runway separation of 5000 feet or more is adequate to permit simultaneous ILS approaches to both runways (reference 25).

Layout 2 has the two terminals separated by the parallel runways, which can be separated by about 700 to 1000 feet to accommodate independent VFR operations. A greater separation would increase the land requirements and involve additional taxiing for any traffic using the short runway and the air-carrier terminal. If a separation of as much as 3000 feet is feasible, Layout 1 is preferable.

Layout 3 has a common terminal area with the long runway adjacent and the short runway beyond. Since light aircraft can use the long runway when the volume of traffic permits, and crossings of a live runway are required only by the light aircraft with a low delay cost, this arrangement is preferred over that of Layout 4 which has the short runway between the terminals and the long runway. This is the least desirable layout and should be used only when required by unusual topography or existing development.

Layouts 5, 6, and 7 have two runways of equal length that are capable of handling the air-carrier traffic. Generally, Layout 5, with a combined terminal area between the runways, will have the greater capacity, the least delays, and the added value of adjoining ground service areas.

Layout 6, with the terminals separated by the closely spaced runways minimizes runway crossings and is generally preferred to Layout 7 with a combined terminal on one side of the two runways. Under some circumstances, Layout 7 may be more desirable than Layout 6, due to the combination of terminal activities in one location.

To achieve greater capacity. Layouts 1 and 5 could be expanded to dual parallel runways on one or both sides of the terminal area.

B. LENGTH OF SECONDARY PARALLEL RUNWAY

When it is necessary to provide capacity beyond that available on a single runway layout at an air-carrier airport, the question arises as to the best way of providing added capacity. Should a runway of length equal to the one now in existence be built, or would it be more economical to provide a short parallel runway to increase the airport capacity? Criteria have been developed to provide a designer with the following information:

1. Figure 5-2 shows the optimum secondary-runway lengths to get the maximum capacity from the pair of runways and the approximate airport capacity.
2. Table 5-I shows the capacity that will result from various lengths of a secondary parallel runway and for various mixtures of aircraft population.

The aircraft populations have been selected to encompass those that are found in various airports across the country (Table 5-II). The capacity figures are for an optimum runway turnoff layout (Figures 5-3 to 5-7 and reference 7). Runways having less desirable turnoff facilities will have smaller capacities. Capacity has been determined by the technique of evaluating delay as described in reference 26. The technique involved finding, for each population, the distribution of population between parallel runways to give the highest capacity.

Layouts showing the exit taxiway system and the relation between the parallel runways have been developed. The basic schemes of Figure 5-1 are used with various runway lengths as shown in Figures 5-3 through 5-7. High-speed exit taxiways in accordance with reference 7 are used on runways with a length of 5000 feet or more. Three right-angle exits are used on the 3500-foot runway at the 700-, 1750-, and 2250-foot points. On the 2200-foot runway, two right angle exits are used at the 700- and 1500-foot points.

It should be noted that a runway configuration such as shown in Figure 5-5 involves a serious runway crossing problem, since all of the aircraft using the outer runway must cross the inner runway. The somewhat unusual taxiway layout to the ends of the short runway is planned to permit handling of the crossings without decreasing the total capacity of the two runways. By use of reference 26, one can determine the locations for crossings of the main runway in order to achieve the desired crossing rate. To achieve the high rates necessary for maximum capacity operation it will generally require that the crossings be near the approach end of the runway. Thus in Figure 5-5, during capacity operation, it would be neces-

TABLE 5-I

AIRPORT CAPACITY AS A FUNCTION OF SECONDARY-RUNWAY LENGTH

A. 10,000-FOOT PRIMARY-RUNWAY LENGTH

Ratio of Type A and B Aircraft of Total Population	VFR Capacity (operations per hour) — Secondary-Runway Length (feet): None	2200	3500	5000	6000	8000	10,000
0.1	70	95	140	143	*	*	*
0.2	69	79	110	132	*	*	*
0.3	58	65	82	118	*	*	*
0.4	52	58	66	98	111	*	*
0.5	47	49	60	76	109	*	*
0.6	45	48	57	67	103	*	*
0.7	42	**	**	56	93	95	*
0.8	42	**	**	50	90	84	*
0.9	41	**	**	43	74	84	*
1.0	39	**	**	**	68	76	76

B. 6000-FOOT PRIMARY-RUNWAY LENGTH

Ratio of Type B Aircraft to Population of Type B, C, D, and E Aircraft	VFR Capacity (operations per hour) — Secondary-Runway Length (feet): None	2200	3500	5000	6000
0.05	86	152	166	*	*
0.1	82	143	160	*	*
0.2	77	109	152	*	*
0.3	74	97	124	143	*
0.4	70	75	93	128	*
0.5	63	67	70	102	124

* No further gain in capacity can be realized for this population.

** Shorter runway not warranted because of high ratio of larger aircraft.

TABLE 5-II

Ratio of Type A and B Aircraft to Total Population	Percent Each Type Aircraft in Population				
	A	B	C	D	E
0.1	5	5	30	30	30
0.2	5	15	30	30	20
0.3	15	15	25	25	20
0.4	20	20	20	20	20
0.5	30	20	20	20	10
0.6	30	30	20	10	10
0.7	40	30	15	10	5
0.8	40	40	10	5	5
0.9	50	40	5	3	2
1.0	50	50	0	0	0

Ratio of Type B Aircraft to Population of Type B, C, D, and E Aircraft	Percent Each Type Aircraft in Population			
	B	C	D	E
0.05	5	15	30	50
0.1	10	15	35	40
0.2	20	15	30	35
0.3	30	15	25	30
0.4	40	20	20	20
0.5	50	25	15	10

sary to have outbound aircraft use the outer taxiway to the 3500 foot runway end. Inbound aircraft after landing would have to taxi back parallel to the runway, to cross the main runway on the parallel taxiway near the approach end of the main runway. Thus, careful planning of taxiway crossing points will be necessary to achieve the capacities shown in Table 5-I and Figure 5-2.

To use the criteria presented in Figure 5-2 and Table 5-I, the designer must first determine the aircraft population and then proceed as shown in the following example. Assume that the airport population consists of 30-percent Type A and B aircraft, and 70-percent Type C, D, and E aircraft. The major runway is assumed to be about 10,000 feet long to accommodate jet aircraft. However, from Figure 5-2, the maximum capacity of a parallel runway is attained when the second runway is a 5000-foot runway, large enough to accommodate Type C, D, and E aircraft. For this combination of runways, the capacity will be a total in VFR of 118 operations per hour. Table 5-I can be used to determine the increase in capacity that would result by building (1) a 2200-foot runway, (2) a 3500-foot runway, or (3) a 5000-foot runway. This table indicates that the capacity of the 10,000-foot runway alone is 58 operations per hour. When a parallel 2200-foot runway is added, the total capacity is 65 operations per hour; with a 3500-foot runway, the total capacity is 82 operations per hour; with the 5000-foot runway, the capacity is 118 operations per hour. Thus, it may be possible, through a staged program, to defer construction for a substantial period of time and still have the necessary capacity available. For each airport development project, a benefit-versus-cost analysis should be made covering the particular conditions of weather, traffic, and facility layout.

Since we are considering the gain in capacity at an air carrier airport, the IFR capacity of any added runway facilities will be important. Generally it will be found that the IFR capacity of the open parallel runway layouts (such as Figure 5-3) will be adequate. However, the close parallel layouts (such as Figure 5-5) will generally be found to have inadequate IFR capacity. (For IFR, runways with a separation of less than 5000 feet can only have one ILS by today's criteria stated in reference 25.) Although IFR capacity may be somewhat less than the VFR capacity, the IFR demand is reduced since a good proportion of the light general aviation aircraft will not be operating. An example of IFR capacity in 1970 (reference 26) will clarify the above:

For the last population under B, Table 5-I,

VFR capacity or demand 124 per hour
IFR demand approximately 90
IFR capacity open parallels 100
IFR capacity close parallels 63

Thus, despite the decreased IFR demand, the close parallels have inadequate capacity. The importance of this to the total airport plan can be evaluated by the procedure presented in the following section.

C. PRACTICALITY OF SEPARATE FACILITIES

The information in Figure 5-2 and Table 5-I provides the designer with a guide as to the gain in capacity achievable with a parallel runway. To determine in greater detail the most economic plan of action, several procedures are involved.

Applying these procedures to a local situation will indicate whether separate facilities should be provided or whether the facilities for general aviation can best be combined with air-carrier facilities.

The steps involved in applying the criteria are:

1. Determine the aircraft population and air- and ground-traffic flow,
2. Analyze the efficiency of runway configurations,
3. Analyze the weather conditions to determine the runway use patterns,
4. Analyze the possible location of general-aviation terminal and service facilities,
5. Predict the traffic for future years,
6. Analyze the capacity of the various runway configurations,
7. Analyze the economics of the various runway configurations,
8. Develop the final airport plan.

These steps are interdependent and must proceed on a coordinated basis. Their use is illustrated in Chapter 7.

1. AIRCRAFT POPULATION AND TRAFFIC FLOW

Two factors have a great effect on airport capacity--the types of aircraft operating at an airport and any special traffic procedures that may be used to control flight in and out of the airport in both IFR and VFR weather. A less important, but contributing, factor in this analysis is the ground-traffic flow that should be determined regarding the origin and destination on the airport of both air-carrier and general-aviation aircraft.

The most desirable means of obtaining this information is by actual field observations at the airport under study. Observing the actual situation will provide a good basis for a projection into the future. To obtain this information, it is suggested that a minimum of three peak days of VFR traffic be surveyed during the peak hours. Four or five days

of observations is desirable because the data would include average as well as peak days of the week for that airport. The peak hours should cover the busy 2 to 5 hours of the day. During the survey, the following items should be recorded:

1. Time (to the second) for each aircraft to land or take off, the aircraft type, the runway used,
2. Weather (velocity and direction of wind, ceiling, and visibility) during the period of observation,
3. Aerial traffic patterns used and any possible effect on airport capacity,
4. Ground-traffic flow to determine the location for parking and unloading of both air-carrier and general-aviation aircraft.

In addition to the actual field observation, the local airport management, FAA Airport Engineers and air-traffic control service should be interviewed to determine the current operating situation and future plans. It may also be necessary to visit the Air-Traffic Route Center to discuss IFR traffic flow and any serious limitations on capacity resulting from complications of nearby airports or airspace restrictions.

2. EFFICIENCY OF RUNWAY CONFIGURATIONS

Since runway configuration has a decided effect on airport capacity and operating efficiency, the most efficient runway configurations must be determined. To some extent, available design guides can be used to indicate the relative efficiency of the configuration. However, it may be necessary to perform an actual capacity analysis of various configurations to determine the optimum configuration.

In assessing runway configurations, it is important to examine the change in operations that result from the construction of parallel runways. This is particularly important when the existing airport has intersecting runways. At such an airport, the construction of parallel runways would probably proceed on the basis of adding one runway in the major direction to increase capacity for the majority of the time. This will change the operating pattern, because it will be necessary to obtain maximum use of the single-direction parallel runways before using other runway configurations that have less capacity.

Considering both airport capacity and taxi time between runways and terminals, the runway configuration should be examined to establish the preference of runway use, giving the highest priority to the runways providing the most efficient operating situation. It is suggested that a good way

to determine this is by an actual survey of current conditions since the most efficient operating runway combination will be apparent. This actual runway preference may be modified substantially by additional runway development.

It is also desirable that the runway combination selected have the same priority of use in both VFR and IFR weather, thereby simplifying operating situations for both the controllers and pilot.

3. WEATHER ANALYSIS

The main purpose of the weather analysis is to determine the proportionate share of time each runway combination is in use, both in IFR and VFR weather. This is necessary because of capacity variations resulting from the use of different combinations of runways. The normal wind rose plot can be used to determine the amount of use of each runway combination before an acceptable crosswind is exceeded. The analysis should be accomplished on the basis of a 15-mph (13-knot) crosswind component since it is commonly used for airport analysis and in actual operating situations. The analysis should be accomplished for both VFR and IFR weather conditions.

4. LOCATION OF GENERAL-AVIATION TERMINAL AND SERVICING FACILITIES

The terminal and servicing facilities for general aviation should be located to provide optimum and efficient operation. Some of the key factors involved are:

1. Accessibility to major highways,
2. Minimizing taxiing distances for aircraft,
3. Minimizing runway-crossing problems for aircraft,
4. Accessibility of the air-carrier terminal where additional facilities are available,
5. Accessibility of pilot aids such as weather, NOTAMS, flight-plan filing, etc.

5. TRAFFIC FORECAST

A traffic forecast for at least 10 years (if possible, 20 years) should be prepared from the information collected together with indications of traffic growth. These forecasts should include the following items for each airport:

1. Growth of aviation by use (air-carrier, general aviation, and military),
2. Breakdown of air-carrier aircraft anticipated,

3. Breakdown of general-aviation aircraft anticipated, together with the amount of local and itinerant flying expected,

4. Volume of traffic during peak hours.

6. CAPACITY OF VARIOUS RUNWAY CONFIGURATIONS

An analysis of airport capacity is necessary to determine how peak-hour demand matches the available capacity and to subsequently perform an economic analysis of airport construction programs. First, operating rate versus delay curves must be developed. The practical capacity should be considered as the operating rate occurring when the following average delays result (reference 26).

Aircraft Population	Average Delay (minutes)
Type A and B aircraft constitute more than 10 percent of total population	4
Type A and B aircraft constitute between 0 and 10 percent of total population	3
Type C, D, and E aircraft only	2

The choice of the three delay values is based on observations of actual operations. The 4-minute delay has been found to be a reasonable value where a volume of air-carrier operations is involved. It is not an optimum condition to have this high a value of delay, but it represents an acceptable condition before additional airport facilities will be requested or provided. On the other hand, with general-aviation aircraft that do not have to operate on a scheduled basis, it appears that the demand decreases if the delay gets too high. The general-aviation user avoids high delays either by operating at different times of the day to avoid delay or by finding other facilities having no delay. Therefore, the lower delay value is selected as being the reasonable practical capacity for planning purposes.

The capacity analysis should be summarized in a manner that shows annual demand against the capacity available on an annual basis.

7. ECONOMICS OF VARIOUS RUNWAY CONFIGURATIONS

To finally determine the runway configuration that should be used, an economic analysis should be performed to compare the operating cost with the annual cost of providing the facilities. This analysis should indicate the development program that has the greatest benefit-versus-cost ratio; this will indicate the configuration that should be used for future planning. The economic analysis should review operating costs for the approach area, runways, and taxiways (Chapter 7).

8. DEVELOPMENT OF FINAL AIRPORT PLAN

With the data that has been compiled, the most efficient airport can be developed. The information that has been collected will also permit the staging of airport development at a rate that will match growth.

Thus, the evaluation of airport planning and construction on this basis is a valuable tool in assessing and determining the proper airport configurations.

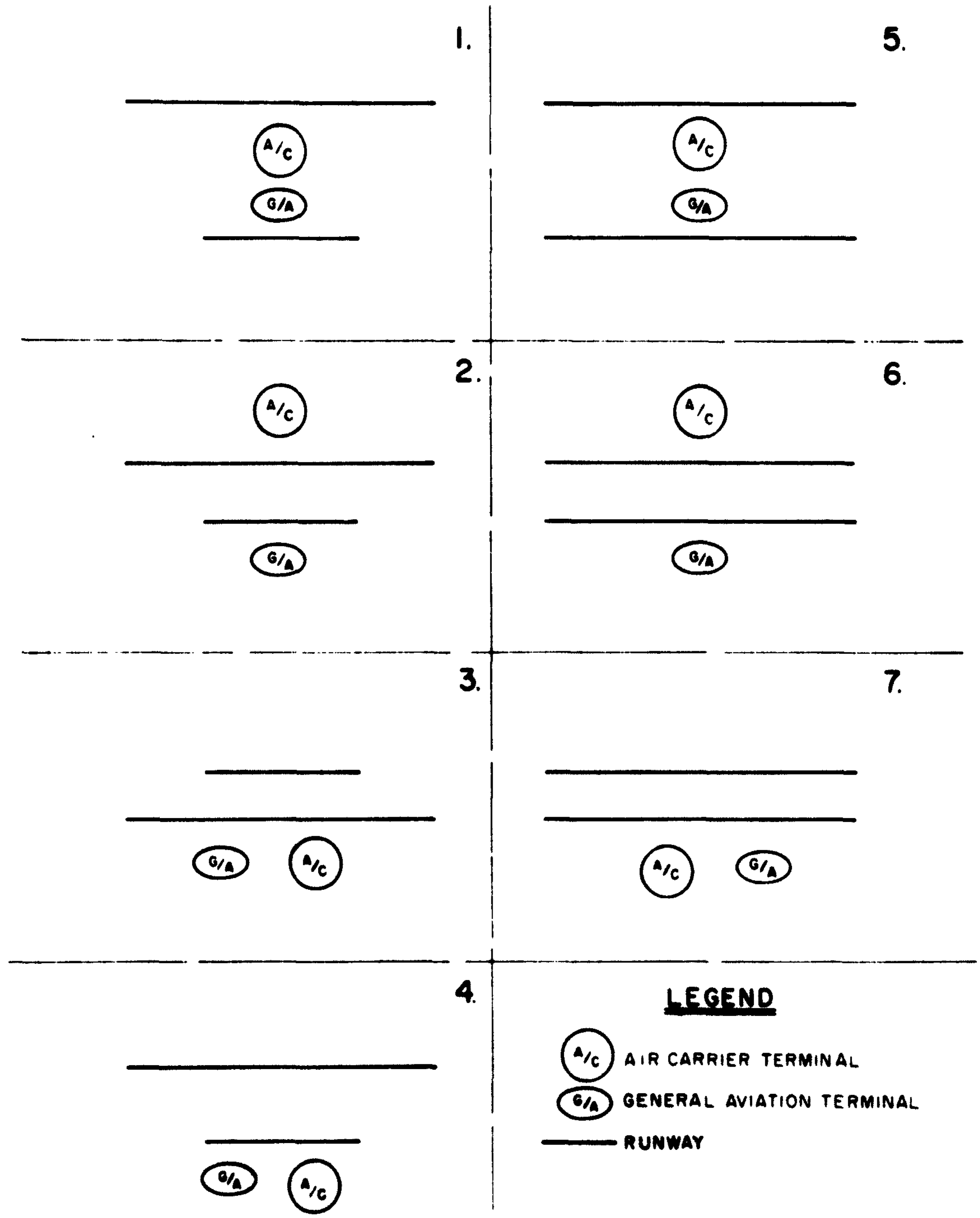
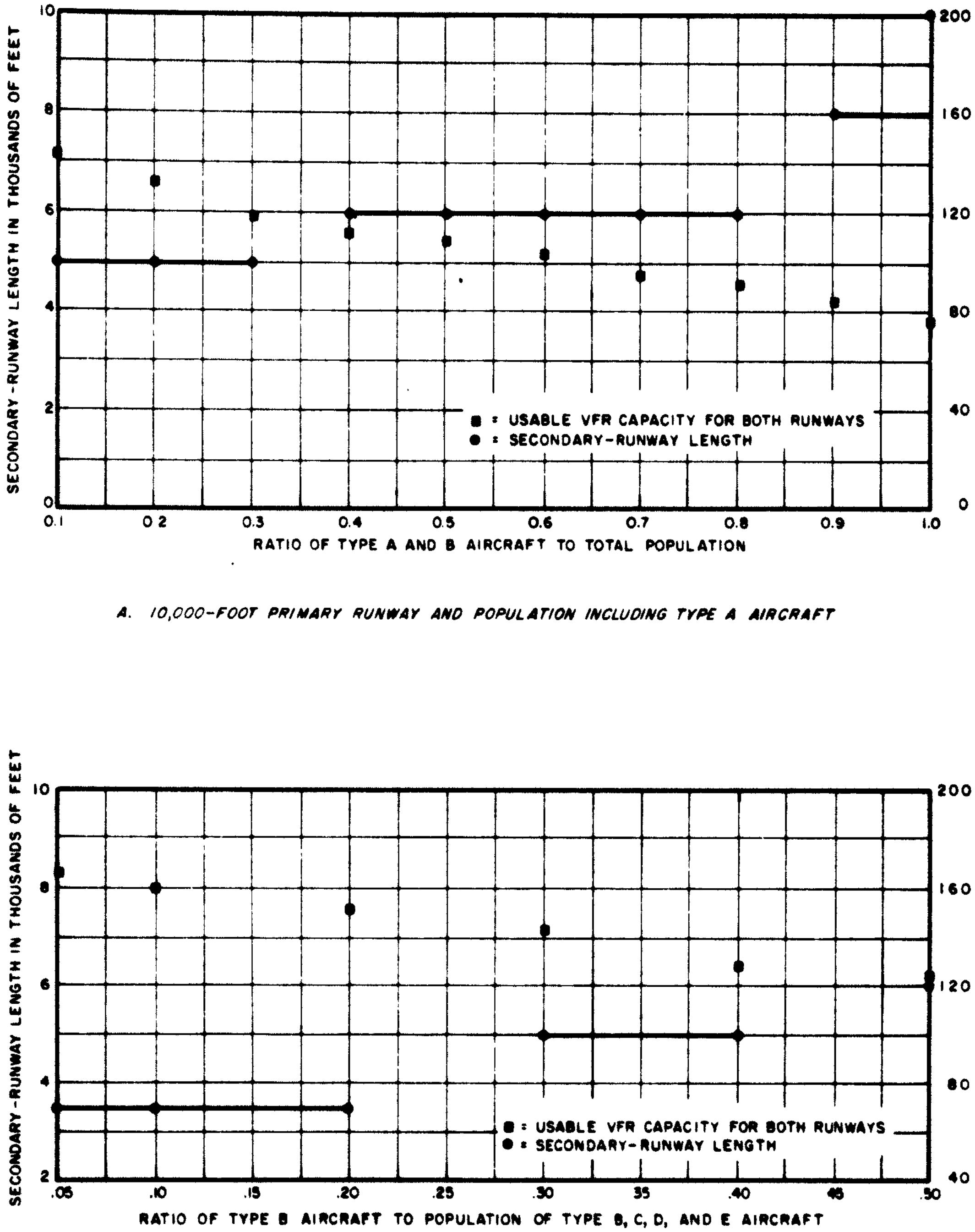


FIGURE 5-1. PARALLEL-RUNWAY AND TERMINAL LOCATIONS FOR GENERAL AVIATION ON AIR-CARRIER AIRPORTS



A. 10,000-FOOT PRIMARY RUNWAY AND POPULATION INCLUDING TYPE A AIRCRAFT

B. 6000-FOOT PRIMARY RUNWAY AND POPULATION WITHOUT TYPE A AIRCRAFT

FIGURE 5-2. SECONDARY-RUNWAY LENGTH FOR MAXIMUM CAPACITY

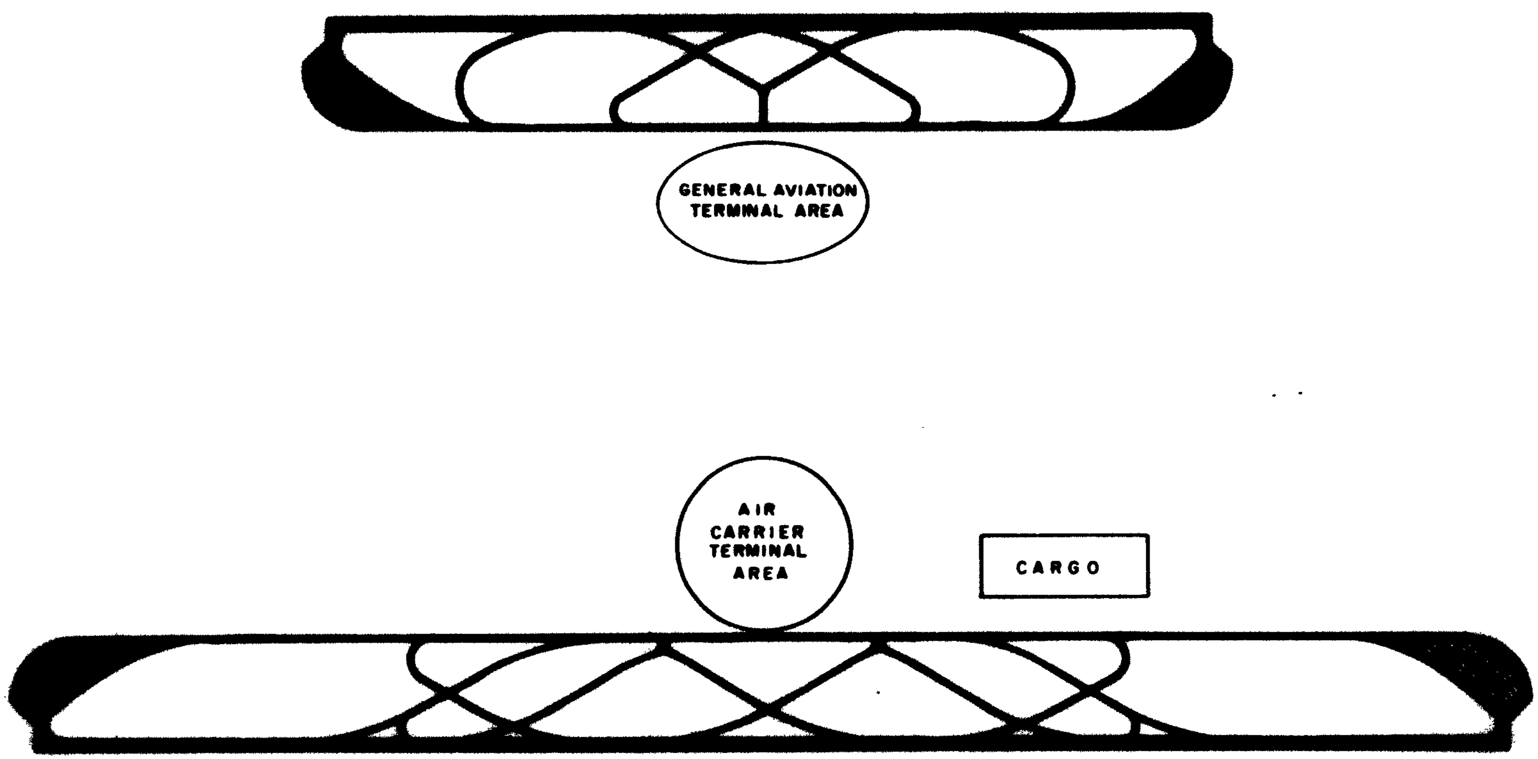


FIGURE 5-3. 10,000- AND 6000-FOOT RUNWAYS WITH 5000-FOOT SEPARATION

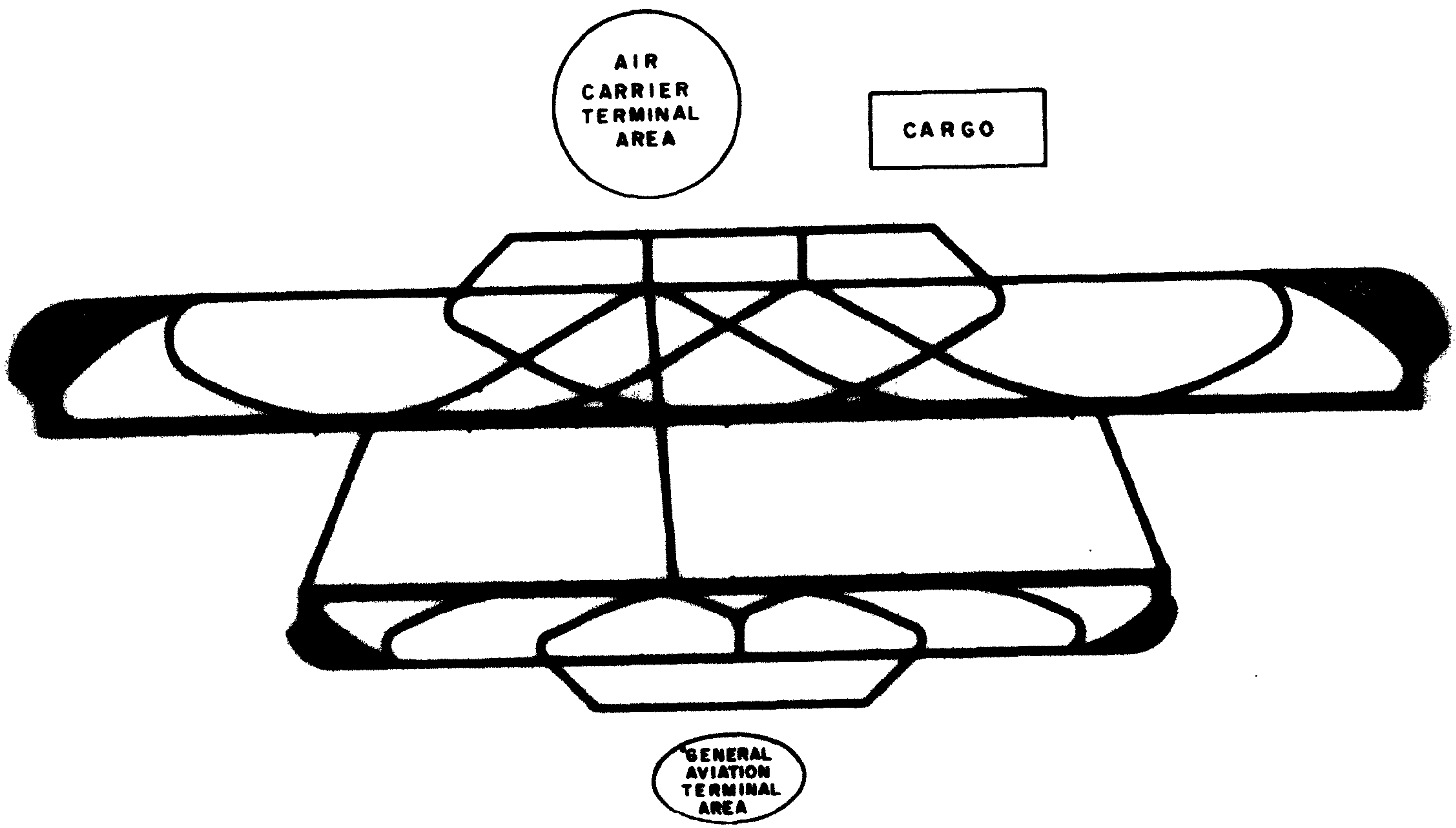


FIGURE 5-4. 8000- AND 5000-FOOT RUNWAYS WITH 1000-FOOT SEPARATION

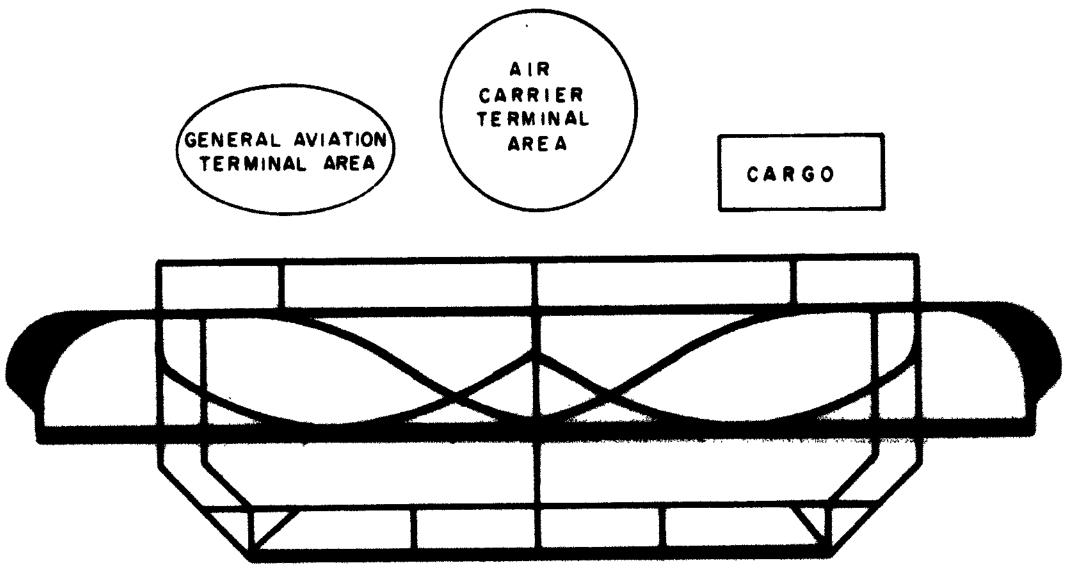


FIGURE 5-5. 6000- AND 3500-FOOT RUNWAYS WITH 700-FOOT SEPARATION

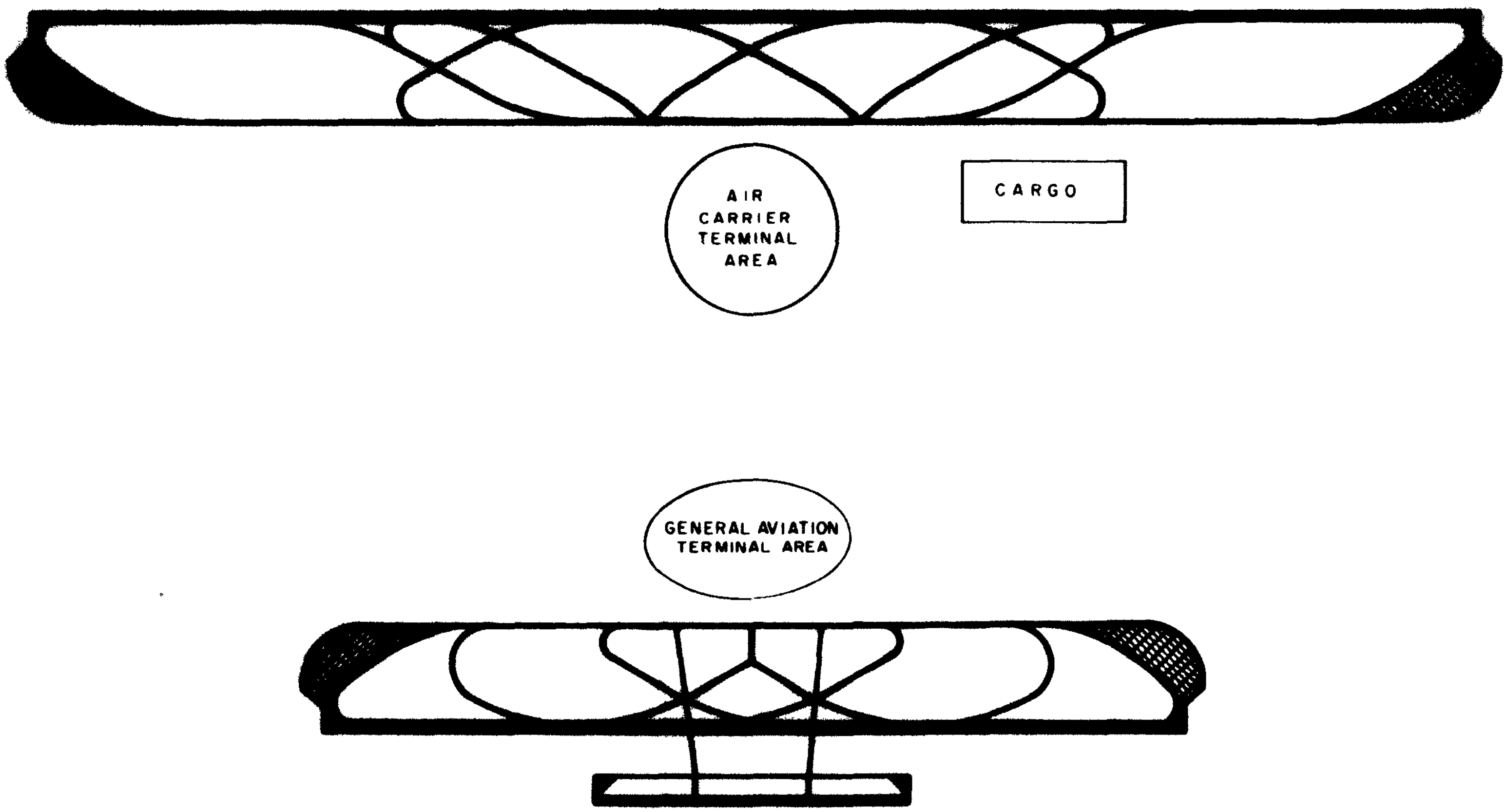


FIGURE 5-6. 10,000-, 6000-, AND 2200-FOOT RUNWAYS

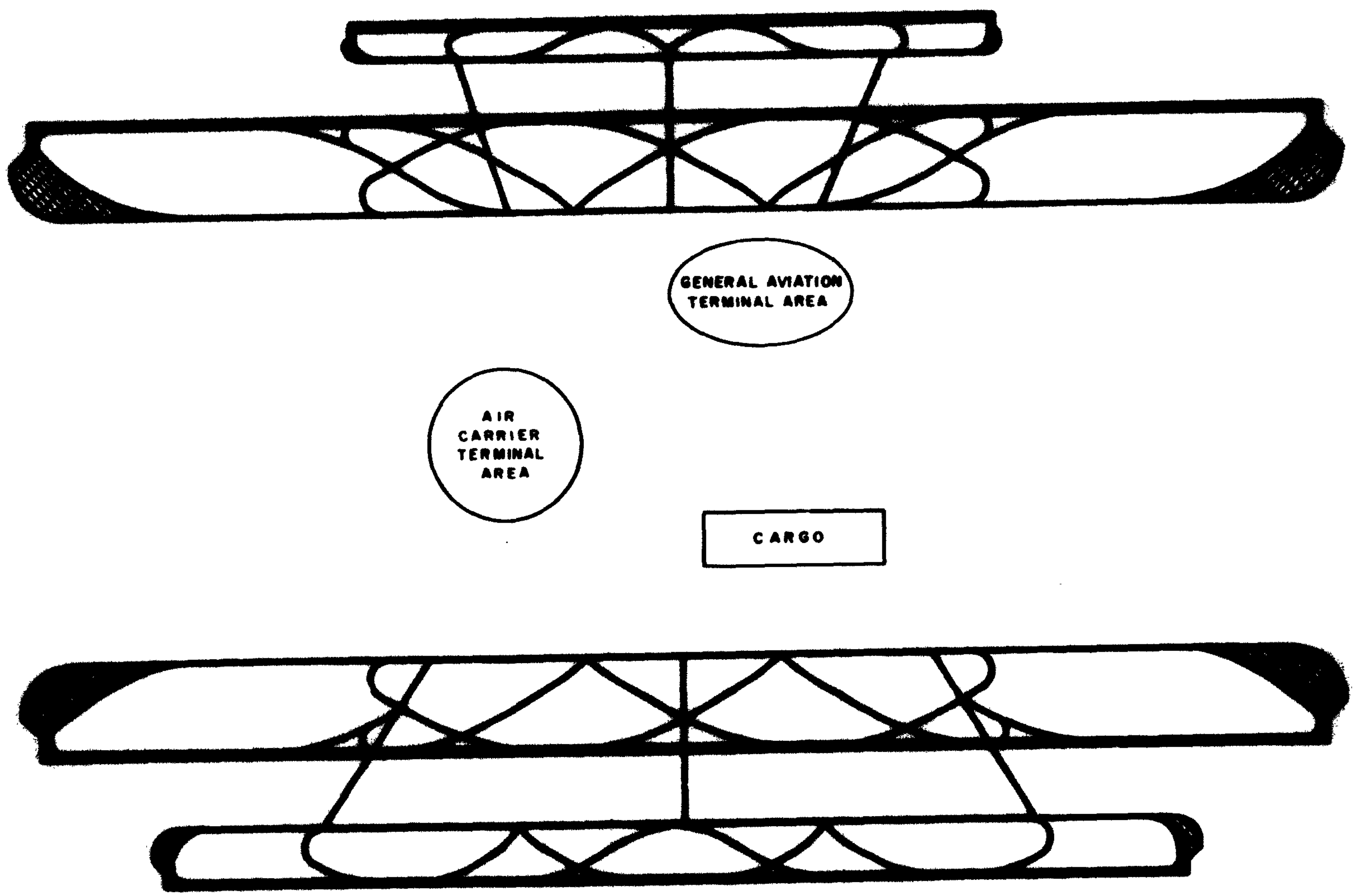


FIGURE 5-7. 8000- AND 5000-FOOT RUNWAYS AND TWO 10,000-FOOT RUNWAYS

VI. AIRSPACE AND NAVAID REQUIREMENTS

Airport owners must submit to the FAA any proposals for modification of landing areas or the construction of new landing areas (reference 27). This mandatory requirement permits the FAA to review the effect on airspace of establishing the modified or new facilities. However, no rules have been established to guide the designer in determining the effect of the facility on the airspace. In 1957, a report (reference 24) prepared for the Curtis Committee attempted to fill this void by suggesting that:

1. Major airports should be separated by 16 miles (measured between the major flow direction of the two airports).
2. Distance along the extended centerline of the instrument-approach direction should be about 40 miles.
3. Instrument runways should have a parallel heading.

It is difficult to develop general criteria that are applicable to all cases where the airspace is involved. However, some criteria would provide better planning than presently exists even if these criteria are not universally applicable.

A. AIRSPACE REQUIREMENTS AND AIRPORT LOCATION

Airspace surrounding an airport is used (1) to progress from one point to another, (2) to approach or depart from a runway, and (3) to perform delaying tactics.

The first function is provided by air routes, the second by final approach and initial departure courses, and the third by holding patterns or by path stretching in vector areas.

Airspace allocation for the first and third functions is subject to geographical adjustment. Such allocation is normally a compromise of many factors, mainly dependent upon navigational practicability and activity at or associated with adjacent airports. Airspace allocation for the second function, however, is dictated by the direction of operation and aircraft performance.

It is important to determine the dimensions of the area immediately surrounding an airport that must not be

violated by an aircraft other than that operating into and out of that airport. For airports having IFR instrument-approach capability, study has indicated that the following rectangular dimensions are required for an airport airspace reservation (Figure 6-1) in a radar controlled area.

1. At airports serving Type C aircraft or larger (Section 4 defines aircraft types)--10 miles in the departure direction, 15 miles in the direction from which approaches will be made, and 5 miles either side of the extended runway centerline. In the case of airports having parallel approaches, the width should be 10 miles plus the distance between runways.

2. At airports serving Type D and smaller aircraft--5 miles in the departure direction, 10 miles in the direction from which approaches will be made, and 4 miles either side of the extended runway centerline.

3. In metropolitan areas requiring more than one airport, the major instrument runways for all airports should be parallel to one another and selected to give maximum lateral separation between airspace reservations. This will optimize air-traffic flow.

In metropolitan areas, airport spacing should generally be planned on the basis that IFR capability will be desired, and thus the above airspace reservations should be used. Should it be desirable to use a VFR spacing criteria, it is suggested that the criteria be a radii of 5 miles for the aiports of (1) above and 3 miles for the airports of (2) above. It may be possible in some cases to permit the VFR criteria of a VFR airport to encroach laterally on the IFR criteria of an IFR airport provided suitable traffic patterns and approach/departure procedures are developed between the two involved facilities.

To obtain the departure requirements, radar films made on a number of days at Idlewild International Airport and Washington National Airport were studied. VFR days were selected and aircraft were observed whose destinations were in a radically different direction from that of takeoff. The reasoning was that turns toward destination would be made as soon as practical. The findings revealed that, at Washington National Airport, which is devoid of jet traffic, the distance to change of takeoff heading rarely exceeded 3 miles. At Idlewild Airport, this distance for jet traffic rarely exceeded 5 miles.

To establish approach-zone criteria, radar films of Washington, Idlewild, and Chicago airports were studied. It was found that common procedure vectored aircraft to intercept the localizer at a point 2 to 4 miles from the outer marker. For safety, an increment of airspace was added to that actually used.

The lesser criteria assigned to the airspace above smaller airports are a result of the better maneuverability of smaller aircraft. With moderately long runways, small aircraft can normally alter takeoff heading before crossing the airport boundary. Low approach speeds, easier control, and smaller turning radius combine to permit a reduction in the required approach area.

The criteria have been designed to permit application of any combination of the airspace reservation. The reservations can touch, but not overlap. Thus, there is adequate space for (1) approach and departure on the runway centerline and (2) two additional tracks offset from but parallel to the runway centerline. A minimum of 3 miles is provided between tracks within an airspace reservation and between adjacent tracks of different reservations. No provision is made for holding within the airspace reservation.

The validity of the dimensions of these areas is indicated by some examples of current activity.

Teterboro Airport is about 9 miles northeast of Newark Airport and is directly in line with the extended centerline of Newark Airport's instrument runway 4. Nevertheless, Newark Airport continues both arrival and departure activities once an approach to Teterboro Airport is established on the localizer and/or radar minimums have been provided.

In a similar fashion, Idlewild Airport continues a highly efficient arrival operation as soon as an approach to Floyd Bennett Airport is 3 miles from and flying parallel to Idlewild Airport's localizer. The touchdown end of Floyd Bennett Airport's runway 01 is about 3 miles from the localizer centerline of Idlewild Airport's runway 4R.

An examination of the New York area will reveal that the distance between the runway 4 centerlines of Idlewild and LaGuardia Airports are about 8 miles. A radar buffer area has been established between the airports. The 8-mile area equally divided would place the buffer 4 miles from each. To permit uncoordinated, independent operation, each must avoid the 1.5 miles of its area that is contiguous with its neighbor to ensure 3-mile separation. Nevertheless, both towers continuously use the remainder of this obviously limited airspace as vector area.

A similar situation exists in Washington, D. C., between Washington National Airport and Andrews Air Force

Base. The buffer line on the current arrival chart for that area is less than 5 nautical miles from Washington National Airport and still less from Andrews Air Force Base. Avoiding the 1.5-mile safety zone, Washington National Airport approach control runs one of its main traffic lanes through the remaining area, vectoring aircraft from Riverdale, which is east of the airport, before turning on the runway 36 localizer.

Both the 5-mile lateral dimension allocated to larger aircraft and the 4-mile dimension specified for smaller aircraft exceed the areas cited in these examples.

The feasibility of establishing a new airport near an existing airport or complex of airports will always be a point of controversy. However, little objection is raised to plans to add additional runways. The new construction will, to a greater or lesser extent, reduce the capacity and increase the complexity of existing facilities. Possibly at no other location is this more obvious than in the Idlewild-LaGuardia-Newark-Teterboro complex.

The adverse effect of each of these airports on the others has long been recognized. Obviously, none of the airports can operate at the peak potential that would be indicated if each were considered separately; but it cannot be ignored that the combination of these four airports is handling close to one million operations per year. It would be ludicrous to suggest that three of these airports could be eliminated and that the fourth, which would then be able to operate in an optimum fashion, would be able to achieve this capacity. It is doubtful that one could be eliminated without the additional load on the other three causing greater problems than if all four existed.

Therefore, an additional airport, almost regardless of its proximity to an existing airport, will result in a combined capacity greater than the existing airport.

It is, of course, desirable to achieve the maximum separation between airports that can be accomplished without removing the facility completely from the area to be served. Selection of airport locations must consider many factors in addition to airspace. Airspace requirements must be studied along with the other factors and airspace needs as well as other needs may have to be compromised to obtain the best overall solution to airport locations.

Air-traffic control equipments must be developed to permit more efficient use of airspace, primarily the elimination of holding stacks in the terminal complex areas. This condition can only be achieved with a satisfactory system to permit long, nonholding approach procedures.

Figure 6-2 shows the application of the recommended airspace criteria to the Washington, D. C. area. The estab-

lished major airports are shown along with an airspace allocation to three general-aviation airport locations. These locations have been examined with other locations and it is concluded that a limited IFR capability could be provided if the airports are located as shown. The limited IFR capacity available would satisfy the normal IFR demand for a general-aviation airport, which is estimated to be about 10 movements per hour for a general-aviation airport handling about 165,000 operations.

B. PILOT AIDS

Certain pilot aids are required at any general-aviation airport that has substantial itinerant traffic. Their availability certainly helps the increase of itinerant traffic because they provide services important to safety and the convenience of travel.

1. UNICOM

Unicom service is a relatively inexpensive airport installation (about $500) that provides the pilot with a means of receiving or transmitting non-air-traffic-control information from his aircraft. It is a time-saving convenience as well as a safety device. Maintenance of the Unicom station is inexpensive, and operation of the transceiver is simple. Most of the general-aviation airports that have the other basic facilities also have Unicom.

2. WEATHER INFORMATION

Weather information can be provided to the general-aviation airport from a nearby air-carrier airport by the U. S. Weather Bureau. This information is continually updated and transmitted over a teletype or telephone tie-line; the only expense to the airport operator is the cable mileage fee (about $1.50 per mile per month) and the teletype-printer rental fee (about $60 per month). The rate for this service is fixed on a nationwide basis.

3. AIR-TRAFFIC CONTROL FLIGHT PLANS

Air-traffic control flight plans can be filed by telephone, radio, or in person by the pilot. Although many pilots prefer to file the plans when they are airborne, telephone use on the ground should be encouraged to decrease the communications load. Consequently, airport telephone facilities to enhance this operation are desirable.

Flight Assistance Interphone Circuits will be provided by the FAA at an airport where the following criteria are satisfied (reference 28): "Historically these circuits have been established to provide preflight briefing and flight plan services to pilots of civil aircraft. Flight Assistance Service is directly related to the volume of cross-country or itinerant flying. Criteria predicated on 50 or more active

based aircraft at an airport gives a reasonable degree of assurance of a level of activity and character of airport operations that warrants spending of funds. While the count of 50 aircraft does not necessarily offer the panacea for all situations, experience has proven that the criteria established provides coverage for the greatest need for the service."

4. NOTAMS

Notices to Airmen Messages (NOTAMS) are distributed to airports and/or individuals by the FAA via teletype and the Airman's Guide. NOTAMS contain information on the establishment, condition, or change in any aeronautical facility, service, procedure, or hazard. Urgent NOTAMS are appended to weather reports disseminated via teletype discussed in B2 above. All notices to Airmen are published in the Airman's Guide bi-weekly by the FAA.

5. RESTAURANT AND PILOT LOUNGE

One of the most important pilot-aid facilities at the itinerant general-aviation airport is a clean restaurant and modern pilot-lounge facilities. Other airport facilities (such as hangar space, tie-down, fuel, and automobile rental service) are usually available at general-aviation airports.

6. FLIGHT SERVICE STATIONS

Aid to the general aviation pilot is provided by FAA Flight Service Stations at various airports.

The functions of these stations as discussed in reference 29 are:

1. To broadcast weather information to enroute aircraft,
2. To assist enroute pilots in establishing position fixes,
3. To broadcast NOTAM data,
4. To accept VFR flight plans,
5. To give pilots preflight briefings,
6. To provide other helpful information to the enroute pilot.

C. INSTRUMENT-APPROACH EQUIPMENT

Reference 30 defines the prerequisites of a public airport to qualify for an FAA navaid installation.

1. VHF OMNIDIRECTIONAL RANGE (VOR) AND OTHER FACILITIES

Many navaid facilities are in operation throughout the nation. If certain requirements are met, such facilities

can be used as approach aids to general-aviation airports. No changes are suggested in the present criteria for use of the VOR, but their use for instrument approach is summarized briefly below.

Instrument approaches can be made to an airport that is up to 10 miles from a VOR facility (reference 31). If the VOR is further than 10 miles from the airport, operations are normally conducted in accordance with VFR from the facility to the airport. In specific instances, however, a procedure can be established to authorize operations under IFR weather from the facility to a point not more than 6 miles away, provided that a minimum obstruction clearance of 00 feet can be maintained in the final approach area. After that point, operations would be VFR.

IFR operations, with 500-foot minimums, are not uncommon when the VOR is used as an approach aid at airports with reasonable approach areas. The availability of the navaid and procedures has far more usefulness than the IFR instrument-approach capability because of their use in marginal weather to increase safety.

A new VOR installation costs the Government $120,000, and certain prerequisites must be met before such an installation is warranted for instrument approach purposes only (reference 30). The general requirements for omnirange installation for the public airport under FAA sponsorship are:

1. Activity of 200 or more annual instrument approaches,
2. Expeditious movement of traffic to increase safety,
3. Noise abatement in certain situations.

If an airport is already served by an instrument landing system (ILS) for approach procedures, it would be ineligible for a VOR installation for instrument approach purposes only.

2. <u>ILS</u>

At the present time, an ILS installation seems impractical for most general-aviation airports. First, few general-aviation airports could meet the FAA prerequisites (for example, a 5000-foot runway at sea level) for such an installation. The installation is expensive ($450,000 with approach lights), and the bulk of general-aviation aircraft are not equipped with glide-slope receivers. The requirements for an ILS installation at a public airport and those for approach lighting are outlined in reference 30.

Because of the increasing trend in equipage and IFR flight, the future installation of ILS may be warranted

at many general-aviation airports. The availability of an inexpensive low-power ILS system may serve this need by reducing cost and minimizing frequency-interference problems. If the development of the low-cost ILS provides operational equipment, then the criteria for eligibility for the installation of this equipment can be relaxed, both as to the minimum activity level, and minimum runway length.

In a metropolitan area, where a system of airports exists that generally meets the airspace planning criteria outlined in this report, it is most desirable to provide IFR approach capability at general-aviation airports. This will permit greater overall regional capacity and will encourage airport use to provide optimum service to the community. Thus in such a metropolitan airport system, an airport with 50 or more based aircraft should be provided wtih approach procedures. This will provide a qualifying basis identical to that of Interphone Circuits, paragraph B3 above.

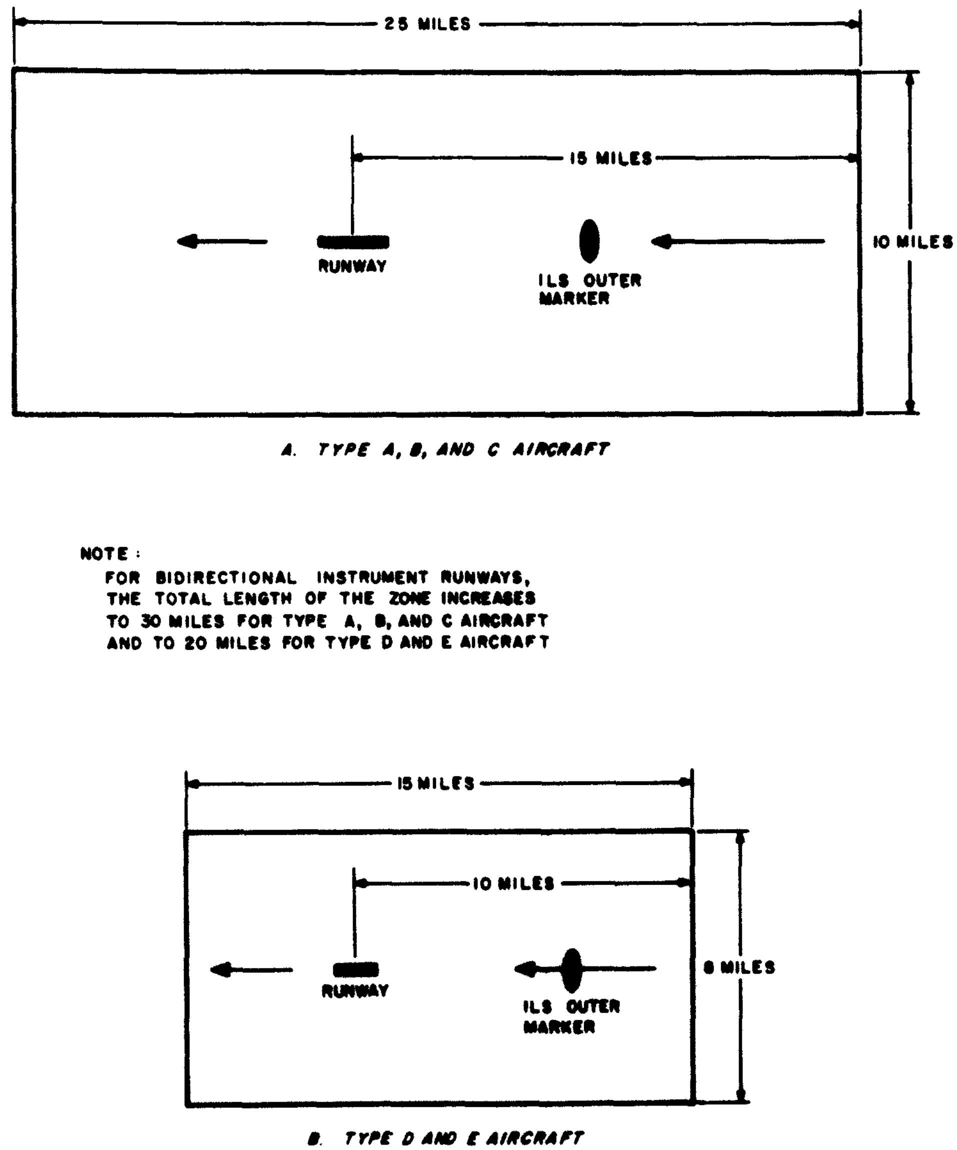
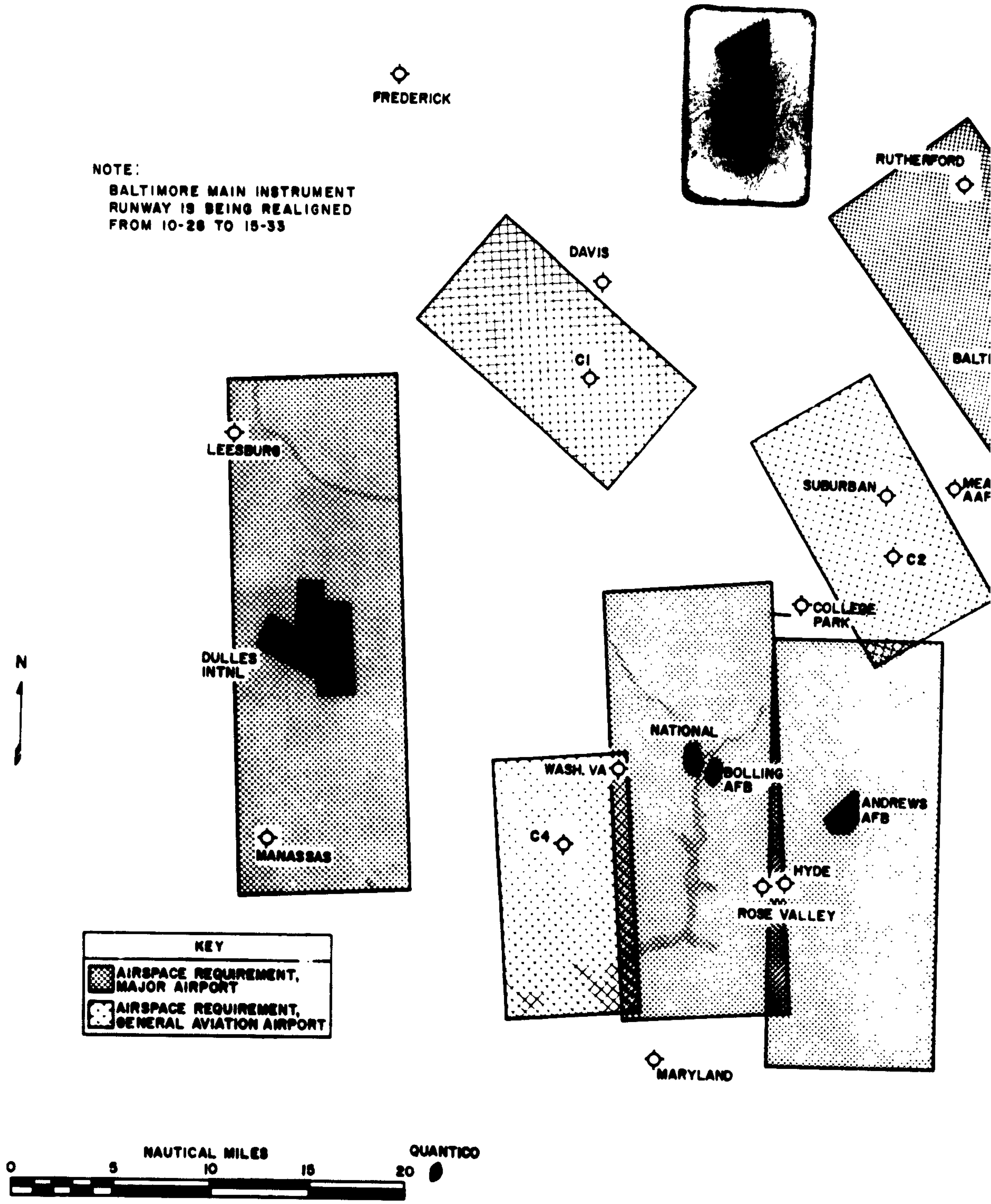
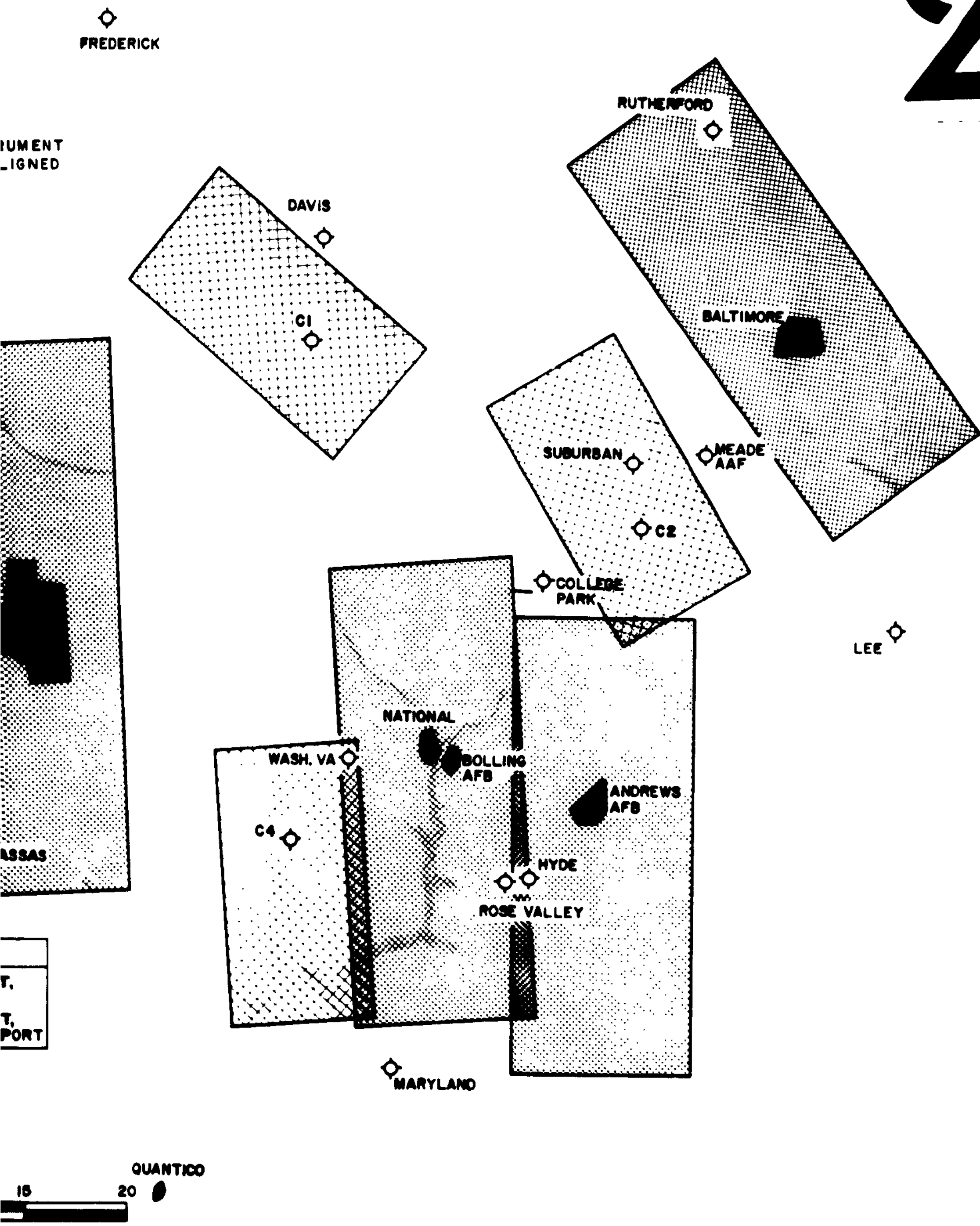


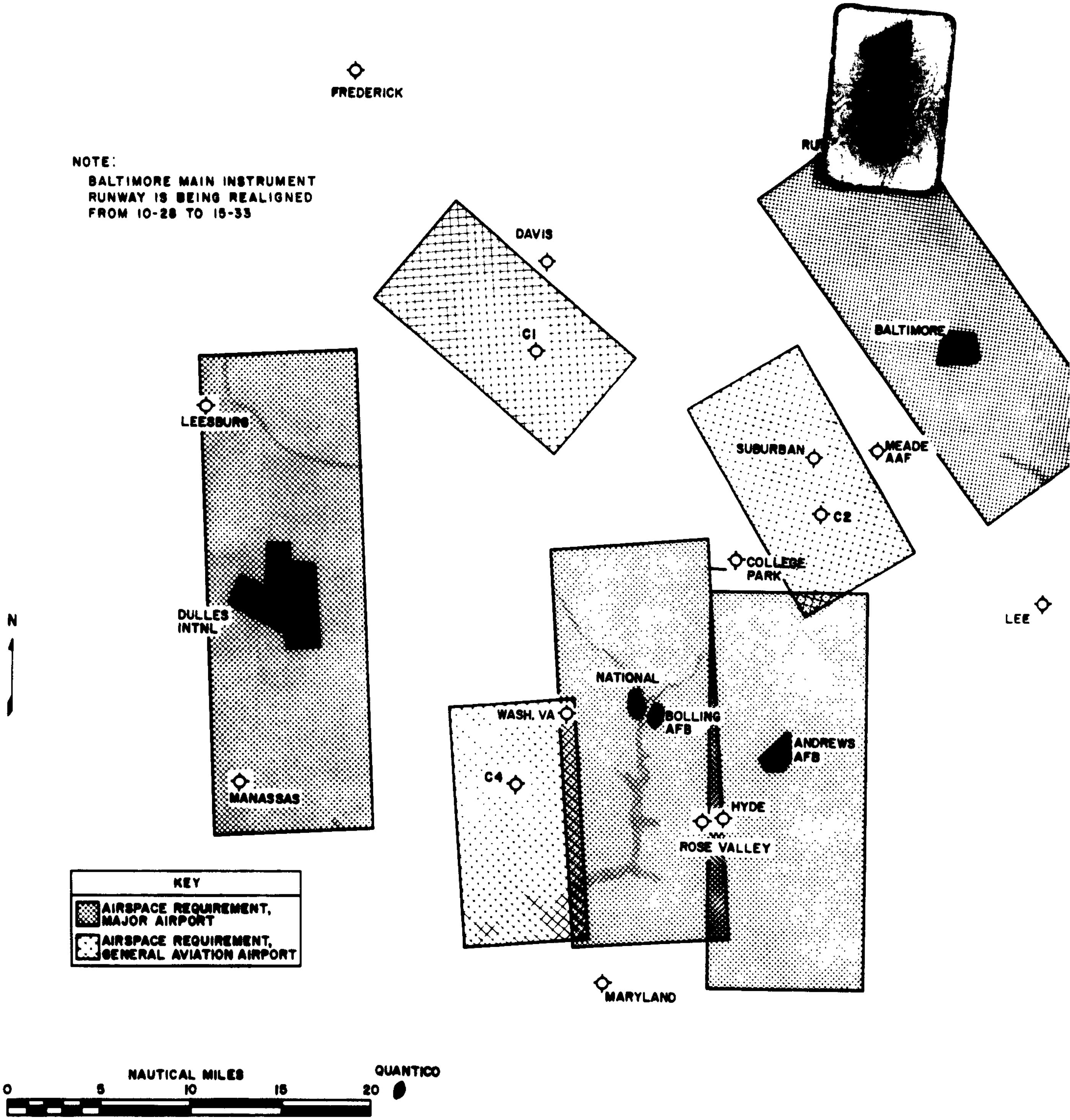
FIGURE 6-1. PLAN VIEW OF IFR AIRSPACE REQUIREMENT


FREDERICK
NOTE:
BALTIMORE MAIN INSTRUMENT
RUNWAY IS BEING REALIGNED
FROM 10-28 TO 15-33
RUTHERFORD
DAVIS
C1
LEESBURG
SUBURBAN
C2
COLLEGE
PARK
DULLES
INTNL
NATIONAL
WASH. VA
BOLLING
AFB
ANDREWS
AFB
C4
HYDE
ROSE VALLEY
MANASSAS
KEY
AIRSPACE REQUIREMENT,
MAJOR AIRPORT
AIRSPACE REQUIREMENT,
GENERAL AVIATION AIRPORT
MARYLAND
N
NAUTICAL MILES
0
5
10
15
20
QUANTICO

2



[illegible] APPLICATION OF IFR A[illegible] [illegible]
[illegible]INGTON PLAN C AIRPORTS


FREDERICK
NOTE:
BALTIMORE MAIN INSTRUMENT
RUNWAY IS BEING REALIGNED
FROM 10-28 TO 15-33
DAVIS
C1
BALTIMORE
LEESBURG
SUBURBAN
MEADE AAF
C2
COLLEGE PARK
LEE
N
DULLES INTNL
NATIONAL
WASH. VA
BOLLING AFB
ANDREWS AFB
C4
HYDE
ROSE VALLEY
MANASSAS
KEY
AIRSPACE REQUIREMENT, MAJOR AIRPORT
AIRSPACE REQUIREMENT, GENERAL AVIATION AIRPORT
MARYLAND
NAUTICAL MILES
0
5
10
15
20
QUANTICO

2

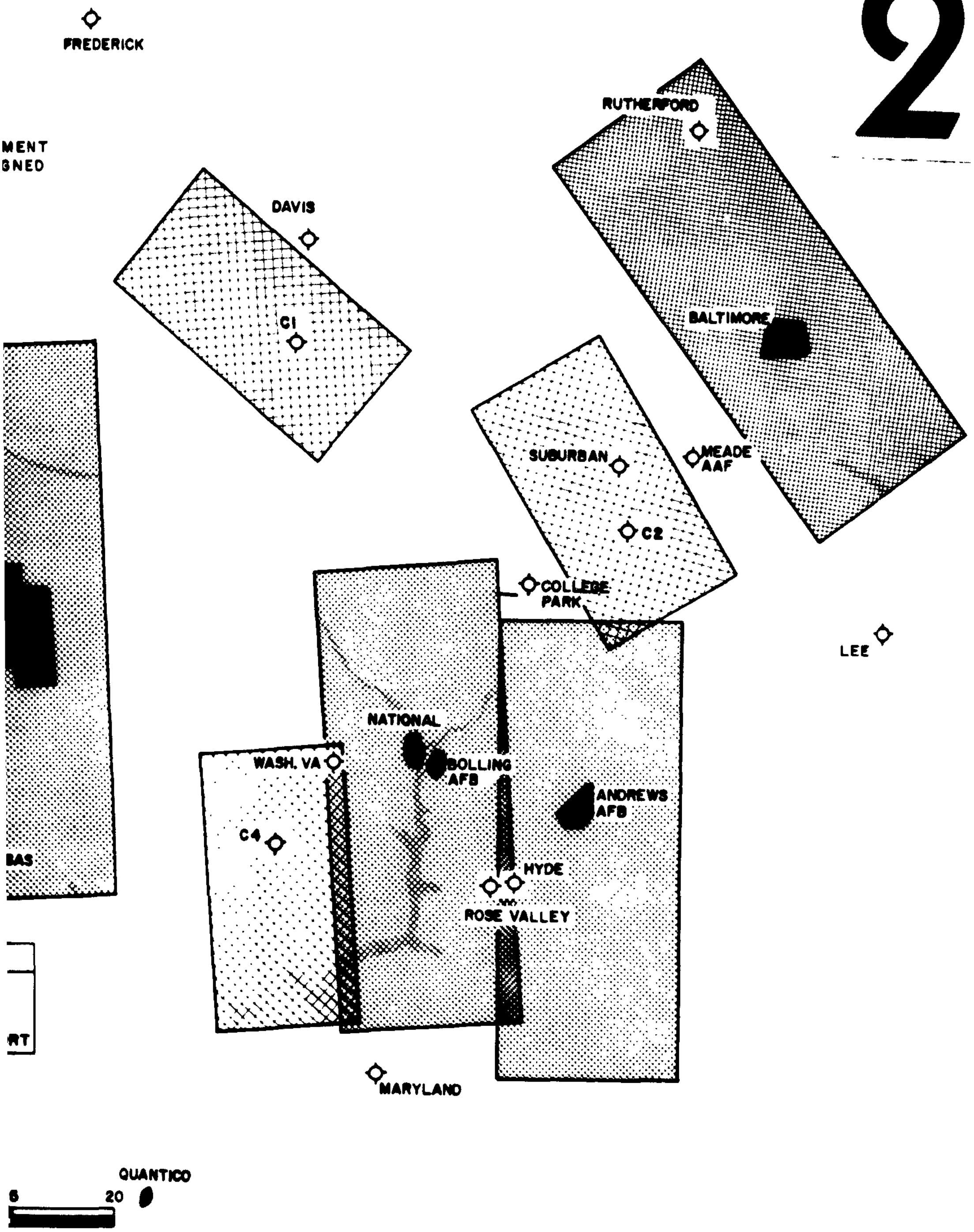


FIGURE -. APPLICATION OF IFR AIRSPACE ... WASHINGTON PLAN C AIRPORTS

VII. CRITERIA USED AT LAMBERT-ST.LOUIS AIRPORT

The existing airport at Lambert Field in St. Louis accommodates air-carrier, general-aviation, and military aircraft. A construction project is now under way to add a short 4600-foot runway to the airport in a direction parallel to the principal runway on the airport, thus giving greater airport capacity when the parallel runways can be used. One of the main purposes of this runway is to help in handling the increasing number of general-aviation aircraft on an air-carrier airport by providing them with a separate runway. This is a good example of an attempt to provide separate facilities for general aviation. It was therefore requested that our criteria be applied to this example as a test of the use of the criteria.

The existing facilities and master plan for the Lambert-St. Louis Municipal Airport (Figure 7-1) provide a location for a shorter runway parallel to and about 1250 feet north of the principal runway 12-30. (The present runways are 12-30, 10,000 feet; 6-24, 7600 feet; and 17-35, 6000 feet.) Runway lengths of 3500, 4600, and 6000 feet are feasible for the shorter runway. The location of this runway makes it just as convenient to the general-aviation terminal area as the existing runways; it will be more convenient to the future general-aviation area on the east side of the airport. Since the air-carrier passenger and cargo terminals are well located south of the principal runway, this is an excellent layout for using a shorter parallel runway for general aviation and concentrating as much traffic on the parallel 12-30 runways as the wind conditions will permit. This is an excellent example to determine the savings or benefits that can be obtained by the use of the parallel runway. It also permits an analysis to determine if a runway length of 3500, 4600, or 6000 feet would give the greatest benefit or maximum benefit-cost ratio.

A. APPLICATION OF CAPACITY CRITERIA

The first step involved in using the criteria is to apply the general criteria indicating the gain in capacity that is possible by adding various lengths of parallel runway.

By 1970, the Lambert Field aircraft population for a Sunday, which is a high-demand period for general-aviation, will consist of 33.4 percent of Type A and B aircraft. However, the weekday situation indicates that Type A and B aircraft will constitute 46.9 percent of the total population.

Thus, for Sunday traffic, the use of the 0.3 ratio in the planning criteria of Table 5-I and Figure 5-2 is indicated; whereas, for weekday traffic, the use of the 0.4 or 0.5 ratio is indicated. The planning criteria indicate that the most efficient operation with Sunday traffic will result from a 5000-foot runway, but the weekday traffic indicates a 6000-foot runway. In either case, a substantial capacity increase is possible. A detailed analysis will now be conducted to determine the most economic solution.

B. APPLICATION OF CRITERIA FOR PERFORMING DETAILED CAPACITY AND ECONOMIC ANALYSIS

Having determined from the general criteria that the best solution for Lambert-St. Louis Airport is to construct a runway from 5000 to 6000 feet long, the criteria can be checked in detail by applying the eight steps of the procedure outlined in Section V.

1. DETERMINATION OF AIRCRAFT POPULATION AND AIR-TRAFFIC AND GROUND-TRAFFIC FLOW

An observer spent one week at the Lambert-St. Louis airport to record operations during the peak hours and to become familiar with both IFR and VFR air-traffic and ground-traffic flow patterns. A work sheet used for observations during peak hours is shown in Figure 7-2. From these observations, three peak 5-hour periods were analyzed to provide a breakdown of aircraft types shown in Table 7-I. The information was used as a basis for projecting aircraft types into the future. The airspace analysis indicated that runway direction 12-30 could be made the instrument approach direction with minor changes in procedures and facilities. Thus, airspace considerations were not limiting on runway planning.

Our analysis of ground-traffic flow was used to point out the need for additional taxiways for the current runway configuration (Figure 7-1). These would provide maximum capacity operation with minimum interference with present runway operations.

2. ANALYSIS OF EFFICIENCY OF RUNWAY CONFIGURATIONS

Figures 7-1, 7-3, 7-4, and 7-5, which show the existing runways and the three stages for a parallel runway, were reviewed in detail to determine the best combinations of runways that would provide high-capacity operations. In daily operations at busy airports, the controller likewise makes maximum use of the most efficient runway combinations or gives them a priority of use. In selecting the priorities, in addition to efficient operating conditions, the length of runway is important so the runways selected can accommodate all aircraft and ground taxi distance is important since it influences overall operating costs. The priority of runway use was developed as shown in Figure 7-6.

TABLE 7-I

PERCENT DISTRIBUTION OF AIRCRAFT OPERATIONS
AT LAMBERT FIELD, ST. LOUIS
DURING PEAK 5-HOUR PERIOD FOR 7, 8, AND 10 JUNE 1962

	Aircraft Operations (percent)							
	7 and 8 June				10 June			
Aircraft Type	Air Carrier	General Aviation	Military	Total	Air Carrier	General Aviation	Military	Total
A	11.3	0	1.6	12.9	8.4	0	0	8.4
B	30.0	0	2.1	32.1	22.6	0	0.4	23.0
C	9.8	8.4	0.5	18.7	7.3	2.7	0.8	10.8
D	0	19.7	0	19.7	0	11.5	0	11.5
E	0	16.6	0	16.6	0	46.3	0	46.3
Total	51.1	44.7	4.2	100.0	38.3	60.5	1.2	100.0

3. WEATHER ANALYSIS TO DETERMINE RUNWAY-USE PATTERNS

The only weather data available was in one grouping of all weather with winds for the 16 compass points and wind velocities of 0, 4, 13, 19, and 32 mph. The runway preferences established were analyzed to determine the amount of usage by assigning all operations to the priority that could be accommodated without exceeding a 15-mph crosswind component.

The amount of time when IFR procedures will be in use was estimated to be 15 percent and assigned to priorities 1 and 2. The percent of use of each runway configuration is shown in Figure 7-6.

4. POSSIBLE LOCATIONS OF GENERAL-AVIATION TERMINAL AND SERVICE FACILITIES

The City of St. Louis has selected a site for the general-aviation terminal that is separate from the air-carrier terminal. It is well-located with respect to the layout of the parallel runway and the analysis proceeded on the basis of having this terminal area available.

5. TRAFFIC FORECAST

The FAA Research and Development Service used the field data collected by AIL and, with the other data available to them, provided to us the traffic forecast indicated in Tables 7-II, 7-III, and 7-IV. This provides all of the forecasts needed, with the exception of the daily distribution of traffic by hours. An analysis was made of the 5-hour intervals observed at the airport, and it was found that a distribution of traffic using an 8-percent peak-hour figure seemed to be reasonable; this was used in our projection of a daily traffic distribution.

6. CAPACITY OF VARIOUS RUNWAY CONFIGURATIONS

Operating-rate versus delay curves were prepared for each runway combination shown in Figure 7-6 with a typical curve being presented in Figure 7-7. These curves were prepared using the handbook for determining practical airport capacity entitled "Airport Capacity" (reference 26). The capacity analysis was then summarized into annual capacity projections (Figure 7-8). These annual summaries show the following:

1. Capacity exhibits large variation with the configuration of the runway that is in use.

2. Peak-hour capacity in 1970 compares most favorably with the peak-hour demand for Plans C and D.

TABLE 7-II

ESTIMATED AIRCRAFT OPERATIONS
AT LAMBERT FIELD, ST. LOUIS FOR 1970

	Operations (thousands)							
Aircraft Type	Air Carrier		General Aviation		Military		Total	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
A	43.8	13.2	0	0	5.8	1.7	49.6	14.9
B	89.7	27.0	0	0	8.2	2.5	97.9	29.5
C	0	0	37.0	11.1	4.7	1.4	41.7	12.5
D	0	0	78.0	23.5	0	0	78.0	23.5
E	0	0	65.0	19.6	0	0	65.0	19.6
Total	133.5	40.2	180.0	54.2	18.7	5.6	332.2	100.0

TABLE 7-III

ESTIMATED AIRCRAFT OPERATIONS
AT LAMBERT FIELD, ST. LOUIS
FOR WEEKDAY IN SUMMER 1970

Aircraft Type	Air Carrier		General Aviation		Military		Total	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
A	129	13.4	0	0	25	2.6	154	16.0
B	265	27.4	0	0	34	3.5	299	30.9
C	0	0	120	12.5	0	0.8	128	13.3
D	0	0	235	24.3	0	0	235	24.3
E	0	0	150	15.5	0	0	150	15.5
Total	394	40.8	505	52.3	67	6.9	966	100.0

TABLE 7-IV

ESTIMATED AIRCRAFT OPERATIONS
AT LAMBERT FIELD, ST. LOUIS
FOR SUNDAY IN SUMMER 1970

Aircraft Type	Air Carrier		General Aviation		Military		Total	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
A	117	10.7	0	0	0	0	117	10.7
B	239	21.9	0	0	9	0.8	248	22.7
C	0	0	60	5.5	16	1.5	76	7.0
D	0	0	215	19.7	0	0	215	19.7
E	0	0	435	39.9	0	0	435	39.9
Total	356	32.6	710	65.1	25	2.3	1,091	100.0

Figure 7-8 shows the amount by which the demand exceeded the capacity; this depends on the runway configuration.

These criteria indicated that, for the Sunday aircraft population (33.4-percent Type A and B aircraft), the optimum runway combination would be a 5000-foot secondary runway with an hourly capacity of 118. In the Lambert Field analysis, Priority 3 with a 4600-foot secondary runway corresponds to the optimum. The curves shown in Figure 7-7 apply to this priority. The capacity is 38 operations on the main runway and 75 operations on the secondary runway; this almost perfectly meets the demand of 33.4 percent Type A and B aircraft, and 66.6 percent Type C, D, and E aircraft. Thus, the capacity is 113 operations--almost equal to the criteria. One should not expect perfect agreement. The criteria is higher because it applies to 30 percent Type A and B aircraft, whereas the actual population is 33.4 percent Type A and B aircraft (40-percent Type A and B aircraft on the same runway combination is 98 operations).

For the weekday traffic (44.4-percent Type A and B aircraft), the optimum runway combination would be a 6000-foot secondary runway with an hourly capacity of 109 to 111 operations. In the Lambert analysis, this would correspond to Plan D and Priority 1; our analysis indicated a capacity of 116 operations per hour. Again, the agreement is considered acceptable. A check of the population used to establish the criteria shows that it involved 20-percent Type C aircraft and 20-percent Type D aircraft, where the Lambert population included 13-percent Type C aircraft and 24-percent Type D aircraft giving Lambert the higher capacity potential. In a broad application of the capacity criteria, such variations will occur because capacity is greatly influenced by local conditions.

Table 7-V gives a more thorough comparison of the Lambert analysis to the planning criteria.

It is considered that the criteria compare reasonably with the Lambert Field capacities except for the 3500-foot secondary-runway capacity of 100, which is 18 higher than the 0.3 criteria 82. The Lambert Sunday population is unusual in that it has only 7-percent Type C aircraft with 59.6 percent Type D and E aircraft. Thus, the 3500-foot secondary runway that will accommodate only Type D and E aircraft is used extensively by about 60 percent of the total traffic. On the other hand, the 0.3 criteria is based on a more normal 25-percent and 45-percent Type D and E aircraft, resulting in a much lighter loading of the 3500-foot runway--only 45 percent of the population can use it.

It is concluded that the capacity planning criteria are satisfactory for the analysis of normal airport operations.

TABLE 7-V

COMPARISON OF LAMBERT ANALYSIS WITH PLANNING CRITERIA

	Ratio of Type A and B Aircraft to Total Population	Operations per hour			
		Primary Runway	Secondary Runway 3500 Feet	Secondary Runway 5000 Feet	Secondary Runway 6000 Feet
Lambert					
Sunday	0.334	*	100 (B5)**	113 (C3)	*
Overall	0.444	*	71 (B5)	85 (C3)	*
Weekday	0.469	49	68 (B5)	83 (C3)	116 (D1)
Criteria	0.3	58	82	118	-
	0.4	52	66	98	111
	0.5	47	60	76	109

* Capacity was not computed.

** The notation B5 identifies this capacity as applying to Plan B, and Priority 5 and similarly for the other symbols.

7. ECONOMIC ANALYSIS OF VARIOUS RUNWAY CONFIGURATIONS

To compute annual airport operating costs, the annual time spent in taxiing aircraft to and from the runways and the delay to aircraft while waiting to use a runway must be found. The same unit of cost has been used in both cases of taxi time and delay time and is a weighted cost based on the following unit operating costs (reference 26):

Aircraft Type	Operating Cost per Minute
A	$13.00
B	7.00
C	3.00
D	1.00
E	0.25

To find the taxi time, each combination of runway use is examined to determine the ground-traffic flow. The taxi distances are then determined and converted to time using taxi speeds of 20 mph in congested areas and 30 mph otherwise.

To find the cumulative delay time, the hourly demand is averaged at two-hour intervals, the delay determined by use of the curves such as Figure 7-7, and this delay summed by day and then for the year.

The costs of Plan C are presented by priorities of runway use in Table 7-VI as an example of the analysis of operating costs. It will be noted that Priorities 7, 8, 9, and 10 have 1 percent or less use. Practically, these can be grouped to average their taxi time and delay time without seriously affecting the accuracy of the results. Table 7-VI gives the accurate costs for these priorities and shows that they represent less than 2 percent of the annual cost. Thus, a good approximation would have been adequate and saved much time. One other item should be noted. Some of the lower priorities have higher capacity than the higher priorities (for example, Priorities 3 and 5). The assignment of priority depends on overall efficiency including taxi costs. Priority 5 is a much less efficient taxi operation and has a less desirable approach pattern.

The annual operating costs are summarized in Table 7-VII. A sizeable reduction in operating costs are shown for Plans B, C, and D. The second runway is built primarily to accommodate general-aviation aircraft. The result

TABLE 7-VI

SUMMARY OF PLAN C ANNUAL OPERATING COSTS FOR 1970

Priority	Practical* Capacity	Days Used	Delay Cost	Taxi Cost
1 VFR	85	90	$255,911	$905,793
1 IFR	62	37	78,529	
2 VFR	91	51	117,416	537,737
2 IFR	62	18	38,330	
3	85	55	42,891	385,800
4	91	73	139,061	553,820
5	100	22	34,480	179,868
6	63	13	120,836	128,556
7	55	0.5	3,479	4,659
8	53	1	7,478	12,484
9	80	0.5	773	4,280
10	80	4	6,181	31,333

* Can be exceeded by about 10 percent during one hour without exceeding the 4-minute average delay.

TABLE 7-VII

SUMMARY OF ANNUAL OPERATING COSTS FOR 1970

Plan	Taxi Cost	Delay Cost	Total Cost	Reduction in Cost Over Plan A
A	$2,809,380	$1,876,869	$4,686,249	0
B	2,834,101	1,343,393	4,177,494	508,755
C	2,744,330	845,365	3,589,695	1,096,554
D	2,752,610	639,080	3,391,690	1,294,559

is to substantially reduce operating costs for the large air-carrier aircraft. This is illustrated by examining the proportionate share of costs due to air-carrier aircraft of Type A and B. Their share of the costs is not constant since it varies with the taxi patterns and delay times for the different runways.

It was found that the taxi cost of Type A and B aircraft was 87.3 and 84.8 percent of the total taxi cost for two typical examples. It was similarly found that the delay cost of Type A and B aircraft was 96.5, 86.3, and 85.4 percent of the total delay cost for three typical examples. Thus, the reduction in cost (Table 7-VII) will principally benefit the Type A and B aircraft.

Since a 4600-foot runway is now under construction at Lambert Field, actual contract prices are available for the capital investment. In view of possible extension of this runway, it is being constructed with heavy-duty pavement to a width of 150 feet. This is considered to be a sound planning decision since the growth of air-carrier activity and possible increased use by military aircraft based or manufactured on the airport may increase the percentage of traffic requiring a heavy-duty runway pavement.

Improvements to the present airport will be analyzed on a benefit versus cost basis for four possible plans or stages of development. On the basis of the bids received for the current contract, estimates of capital improvement costs were made for the four stages. These costs include engineering and administrative costs of about 12 percent of the construction contract.

A summary of the present construction contract costs is:

Site work		$170,000
Paving		555,000
Drainage		70,000
Lighting		175,000
	Total	$970,000

The site-work group includes demolition, grading, and seeding. Table 7-VIII shows the capital improvement costs for the four improvement programs.

To compute the annual costs of the various programs, the cost of financing, maintenance, operation, and repair for each type of improvement was estimated on the basis of a total percent of the development cost. Using a financing cost based on revenue bonds to be retired in 20 years and estimated main-

TABLE 7-VIII

CAPITAL IMPROVEMENT COSTS

	Cost (thousands of dollars)			
	Plan A Taxiways	Plan B 3500-Foot Runway	Plan C 4600-Foot Runway	Plan D 6000-Foot Runway
Site Work	160	150	190	260
Paving	520	360	630	860
Drainage	60	60	80	110
Lighting	160	130	200	270
Total	900	700	1100	1500

tenance, repair, and operating costs, the annual costs used for these analyses are:

Site work	10 percent
Paving	12 percent
Drainage	10 percent
Lighting	16 percent

The annual costs are shown in Table 7-IX.

The final step in determining the benefit-cost ratio is summarized in Table 7-X. This table shows

1. Either a 3500-, 4600-, or 6000-foot runway is economical, with the greater benefit resulting from the 4600-foot runway.
2. Analysis has been limited to the 1970 traffic level. Thus, the analysis does not indicate the earliest year that the parallel runway can be justified. However, the staged program to provide an ultimate 6000-foot runway is justified as part of the long-range improvement program for the airport.

In assessing the above results, it should be remembered that our earlier application of the planning criteria indicated that the secondary runway should either be 5000 feet (corresponding to Plan C--4600 feet) based on the Sunday aircraft population, or 6000 feet based on the weekday population. The detailed analysis indicates either runway length can be justified with the 4600-foot runway giving a slightly greater benefit. Thus, with respect to our main goal of validating the proposed criteria, we conclude that the Lambert Field application has adequately demonstrated the merit and validity of (1) the criteria for runway length and capacity and (2) the technique of economic analysis of facilities.

TABLE 7-IX
ANNUAL COSTS
(Thousands of Dollars)

	Plan A	Plan B	Plan C	Plan D
Site Work	16	15	19	26
Paving	62	43	76	103
Drainage	6	6	8	11
Lighting	26	21	32	43
Total	110	85	135	183

TABLE 7-X

BENEFIT-COST RATIOS

Plan and Runway Length	Annual Cost of Facility (thousands of dollars)	Annual Saving in Operating Cost (thousands of dollars)	Ratio of Benefit-Cost
Plan B - 3500 feet	85	509	6.0
Plan C - 4600 feet	135	1,097	8.1
Plan D - 6000 feet	183	1,294	7.1

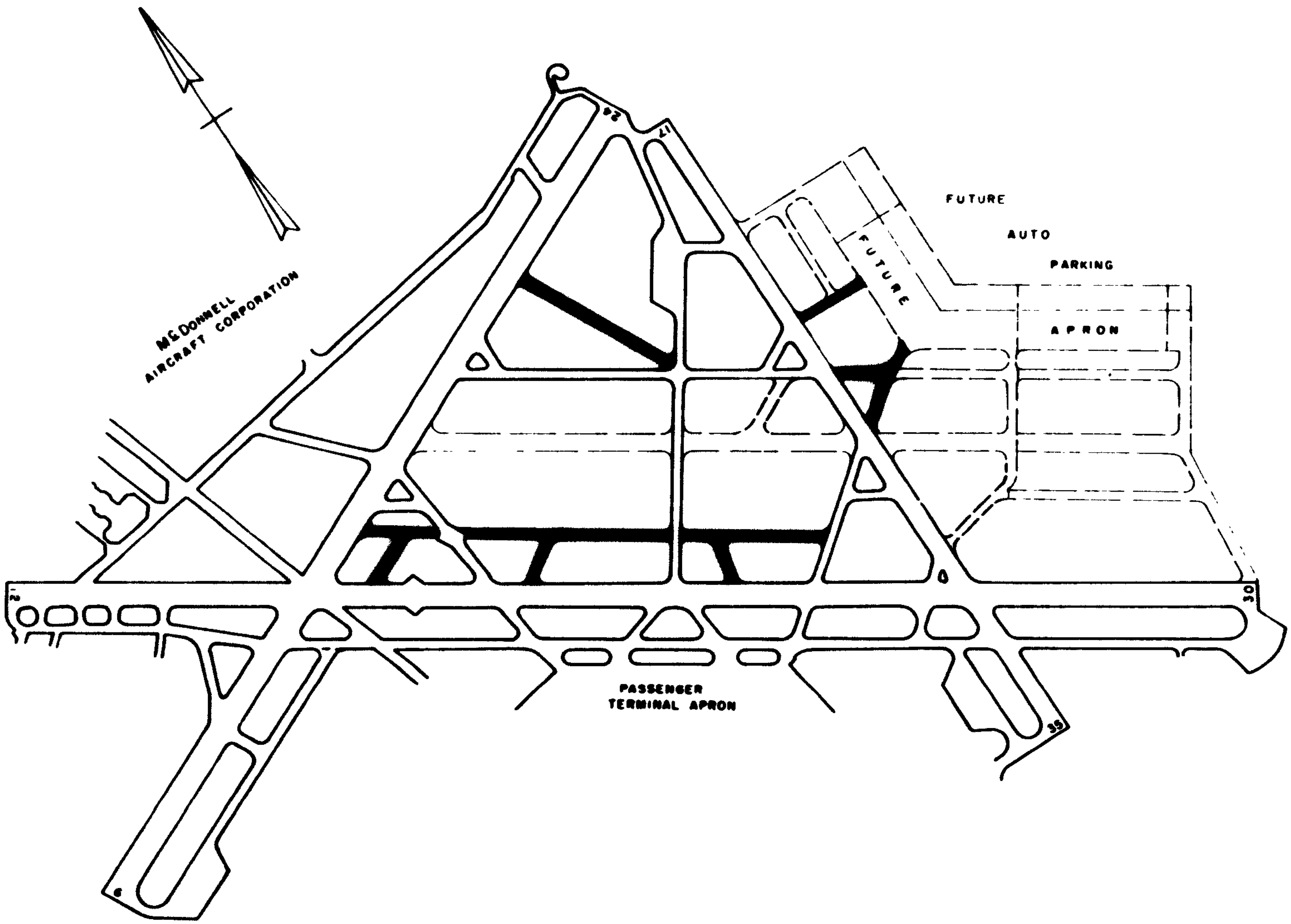
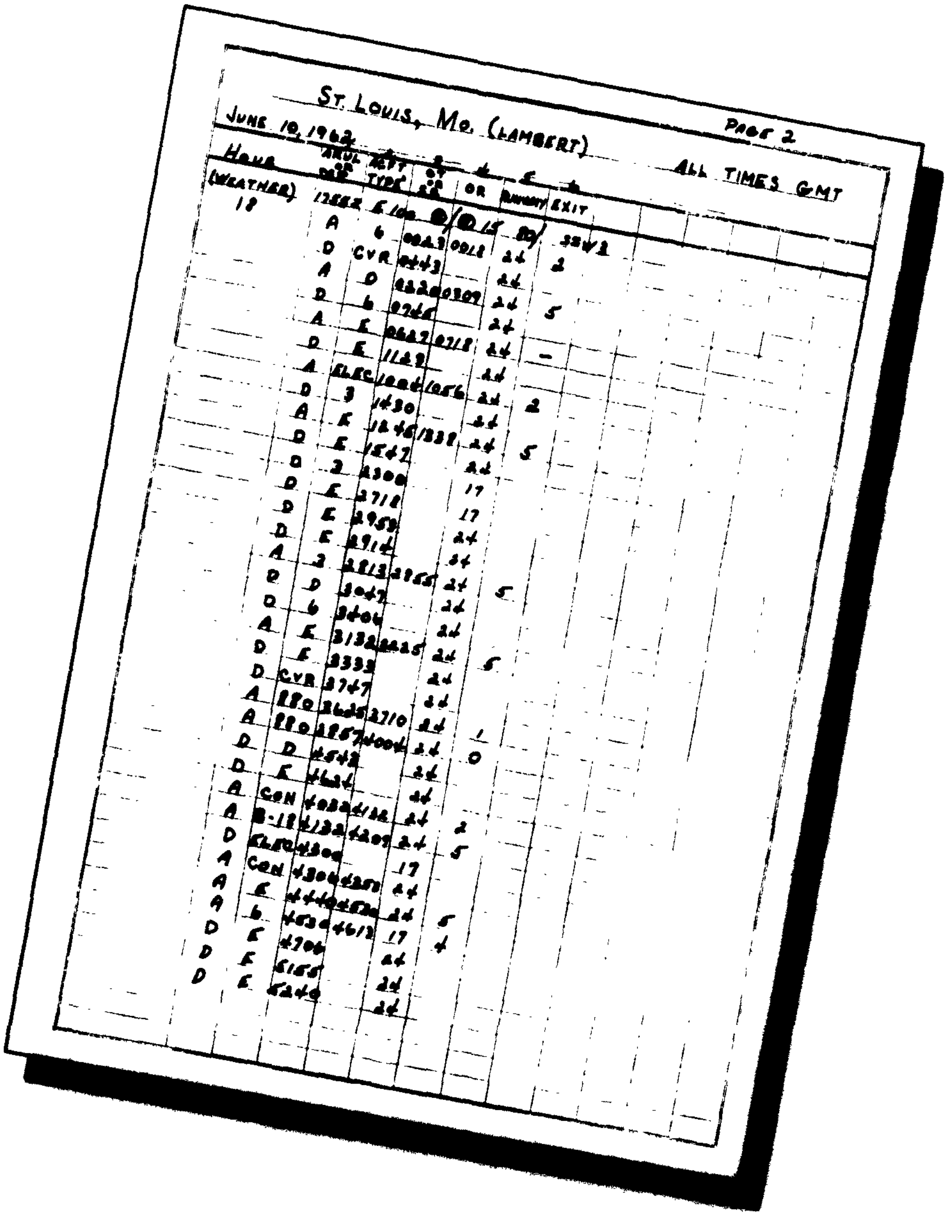


FIGURE 7-1. LAMBERT-ST. LOUIS MUNICIPAL AIRPORT WITH 1962 RUNWAY CONFIGURATION WITH ADDITIONAL TAXIWAYS--PLAN A



St. Louis, Mo. (Lambert)

June 10, 1962 — Page 2 — All Times GMT

Hour (Weather)	Arvl or Dep	Acft Type	OT or SR	OR	Runway	Exit
18	1255Z	E 100	⑩/⑩ 15	80/	35W2	
	A	6	0023	0018	24	2
	D	CVR	0443		24	
	A	D	0323	0309	24	5
	D	6	0746		24	
	A	E	0627	0718	24	–
	D	E	1129		24	
	A	ELEC	1004	1056	24	2
	D	3	1430		24	
	A	E	1246	1332	24	5
	D	E	1547		24	
	D	3	2300		24	
	D	E	2718		17	
	D	E	2959		17	
	D	E	2914		24	
	A	3	2813	2955	24	5
	D	D	3047		24	
	D	6	3404		24	
	A	E	3132	3225	24	5
	D	E	3333		24	
	D	CVR	3747		24	
	A	880	3635	3710	24	1
	A	880	3957	4004	24	0
	D	D	4542		24	
	D	E	4624		24	
	A	CON	4032	4132	24	2
	A	B-18	4132	4209	24	5
	D	ELEC	4300		17	
	A	CON	4304	4357	24	
	A	E	4440	4520	24	5
	A	6	4530	4612	17	4
	D	E	4704		24	
	D	E	5155		24	
	D	E	5240		24	

THE WEATHER SHOULD BE RECORDED WITH EVERY CHANGE SEQUENCE

RUNWAY AND RUNWAY EXIT USED WILL HELP IN THE ANALYSIS OF OPERATIONS

OT = OVER-THE-THRESHOLD TIME FOR A LANDING

SR = START ROLL FOR A TAKEOFF

OR = OFF-RUNWAY FOR A LANDING

FIGURE 7-2. TYPICAL WORK SHEET FOR AIRPORT OBSERVATIONS

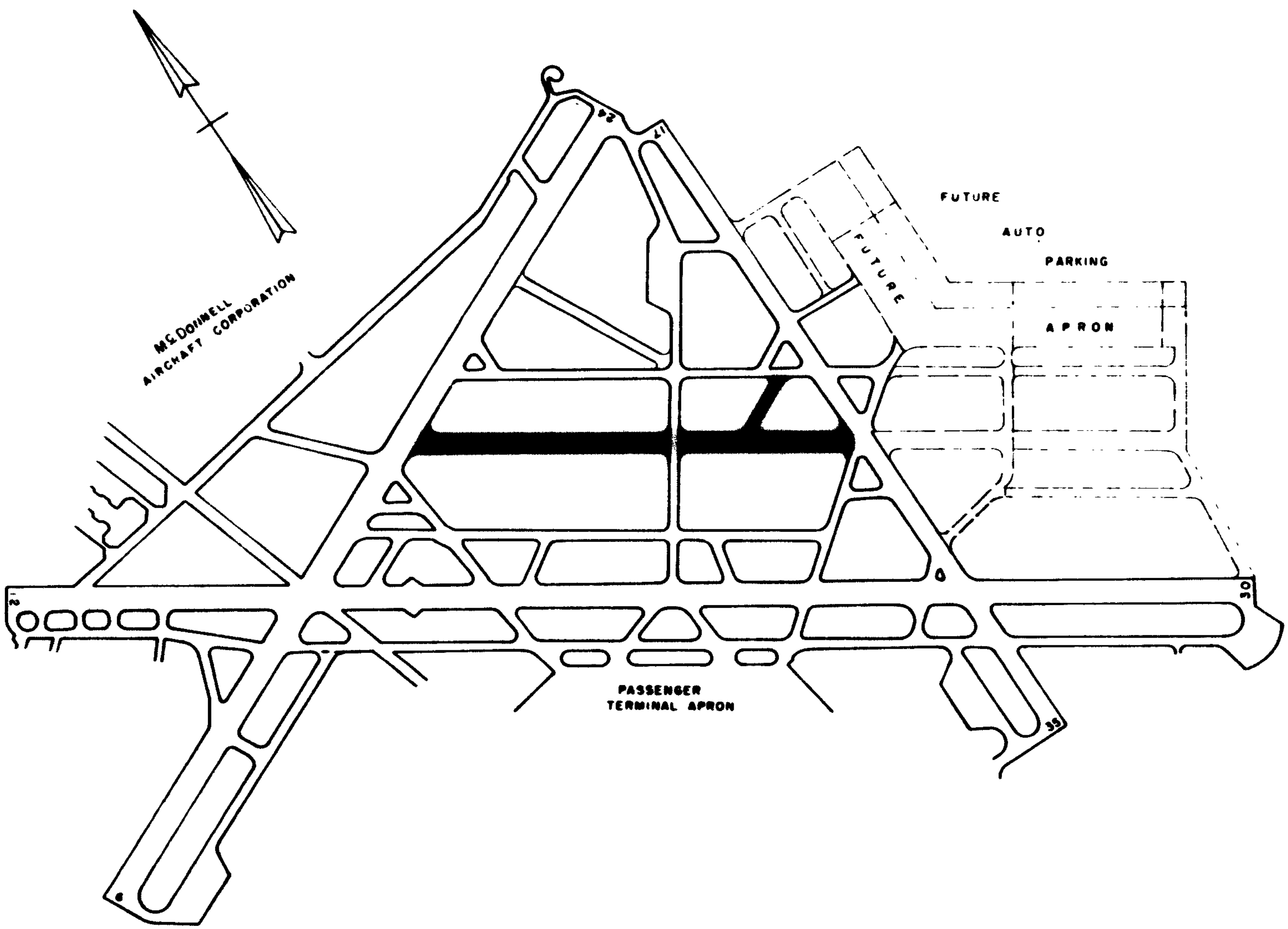


FIGURE 7-3. LAMBERT-ST. LOUIS MUNICIPAL AIRPORT WITH ADDED 3500-FOOT PARALLEL RUNWAY--PLAN B

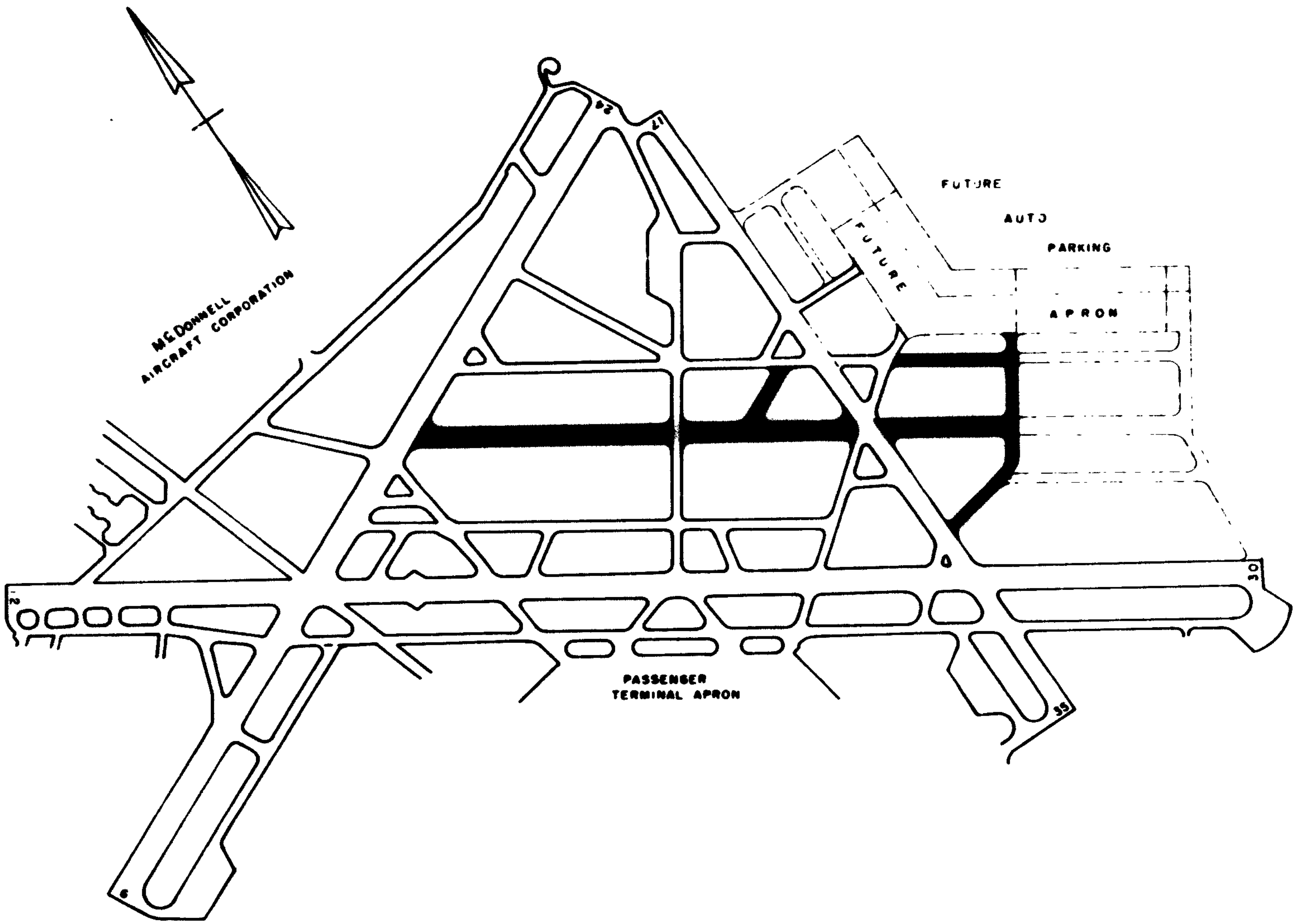


FIGURE 7-4. LAMBERT-ST. LOUIS MUNICIPAL AIRPORT WITH ADDED 4600-FOOT PARALLEL RUNWAY--PLAN C

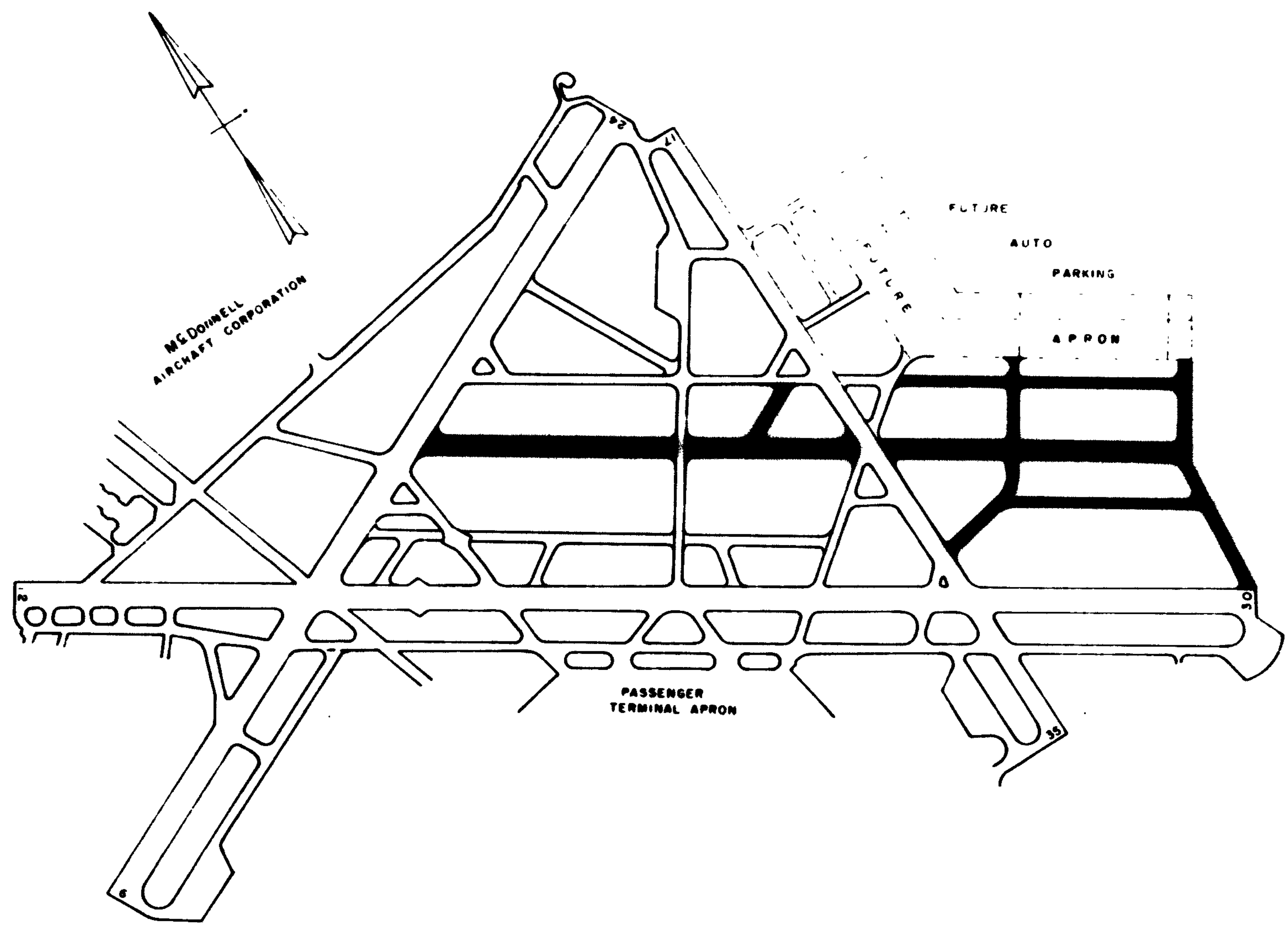
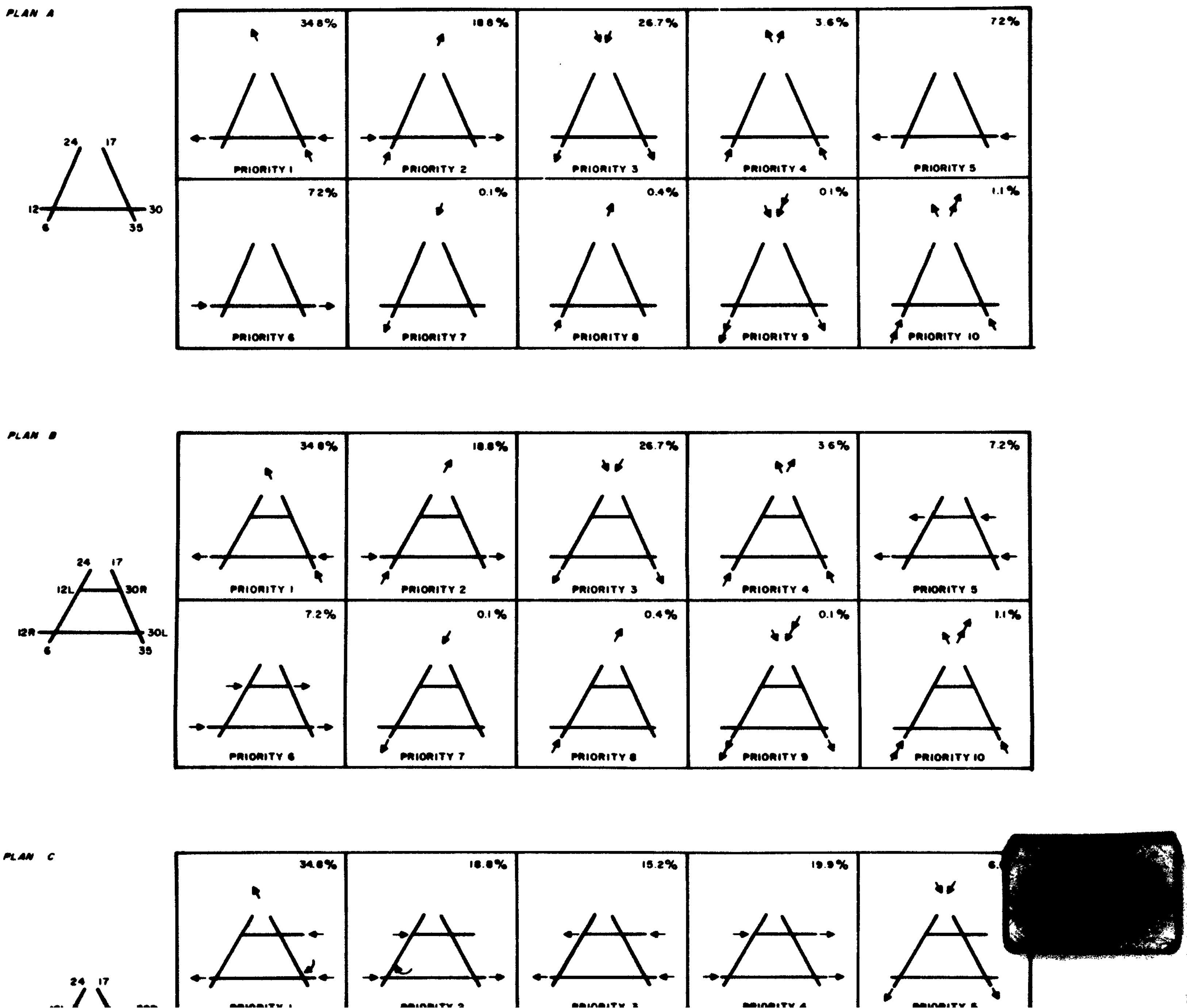


FIGURE 7-5. LAMBERT-ST. LOUIS MUNICIPAL AIRPORT WITH ADDED 6000-FOOT PARALLEL RUNWAY--PLAN D

BASIC RUNWAY CONFIGURATIONS



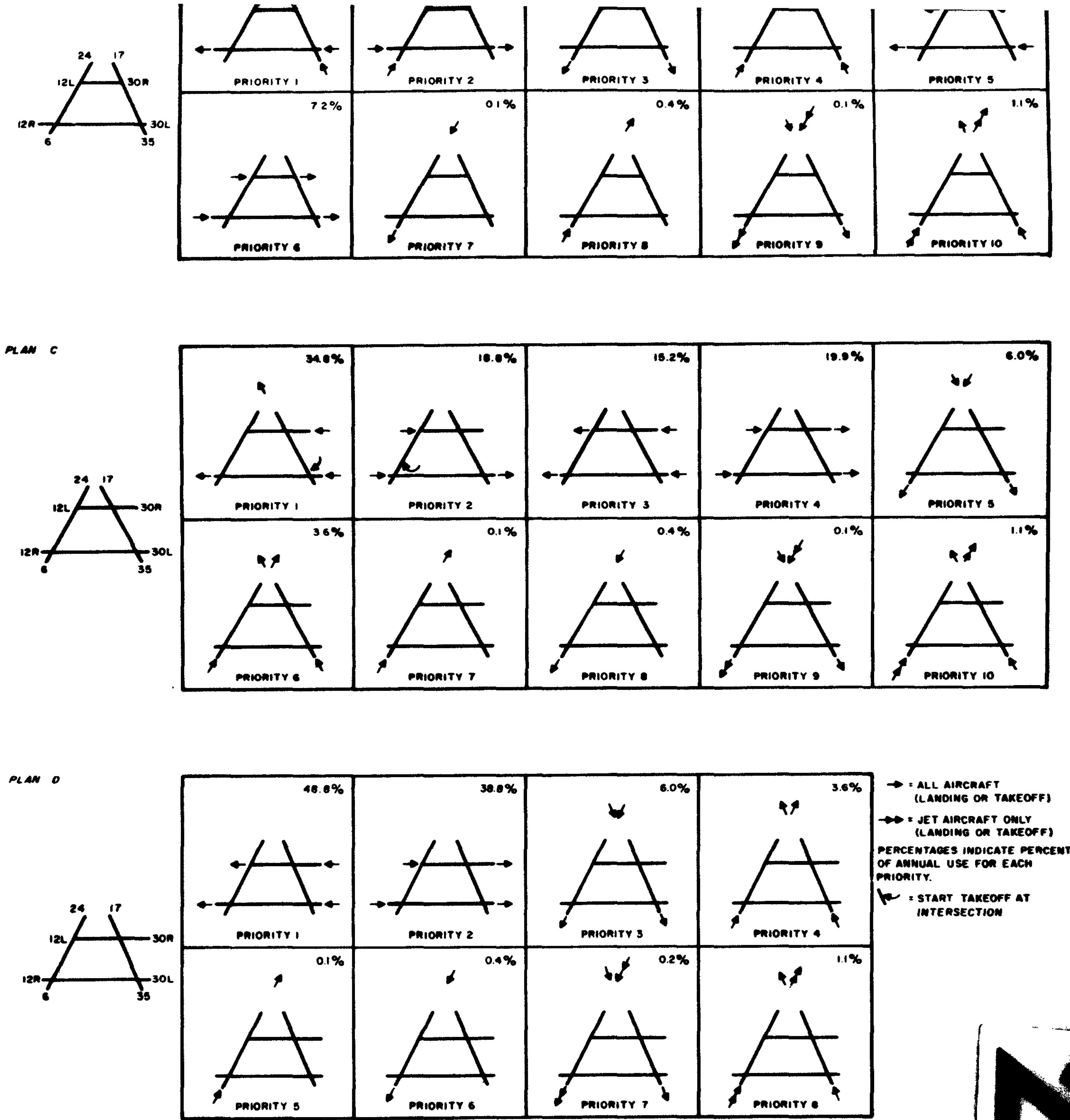


FIGURE 7-6. PRIORITY OF RUNWAY USE

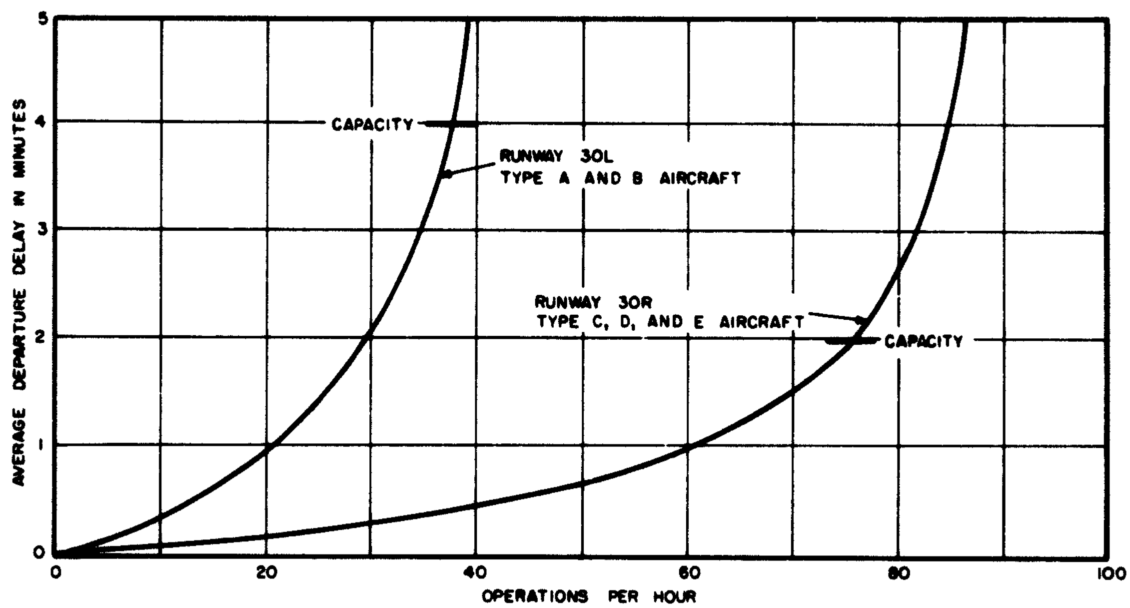


FIGURE 7-7. DELAY RESULTING FROM VARIOUS RUNWAY OPERATING RATES FOR PLAN C AND PRIORITY 3

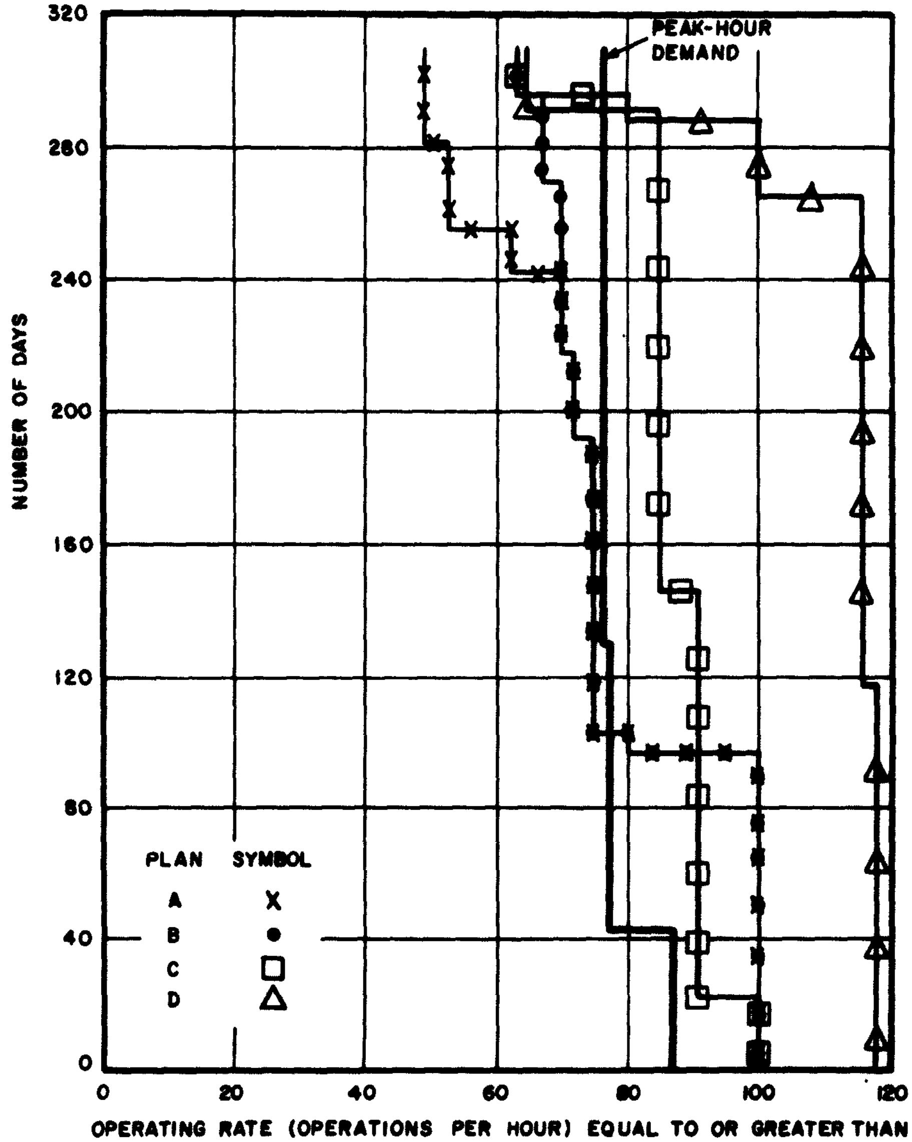


FIGURE 7-8. SUMMARY OF PREDICTED AIRPORT CAPACITY FOR 1970

VIII. ECONOMICS OF AIRPORTS AND GROUND TRANSPORTATION

The economics of general aviation should be based on obtaining for the users the most return for the money expended. Although this is most clearly seen where the benefits and costs are directly entered on the books of the users, the same principles apply when some charges and returns are distributed in a more complex, indirect manner.

Aviation is one of the competing and complementary forms of transportation. There are some things such as aerial photography which cannot be duplicated by other methods, just as there are many things which can be achieved only by surface transportation. For any transportation task the method or combination of methods that provide the highest efficiency or lowest cost should be used.

The major decisions in planning the most efficient system of airports to serve aviation in a metropolitan area cover the number of airports, the locations, and the facilities provided at each airport. Having determined the geographical distribution and magnitude of the potential air traffic, various logical combinations of airports can be evaluated to optimize the benefit cost relation.

Since any airport is dependent on surface transportation to connect with the points of passenger origin and destination, convenience to the major highway network of the area is important. This does not mean the airport must be contiguous or parallel to a major highway unless such a location is most acceptable from all other criteria. The major highways now have limited access and the airport traffic alone may not justify an interchange. On important roads with unlimited access such frontage is often too valuable to warrant the use of up to 1 mile for a general-aviation airport. The prevailing wind, approaches, and topography may indicate a runway direction at an angle to the highway. This does not preclude a location of the building area for the airport where it will have convenient direct access to a major highway.

The convenience of an airport to the user's points of origin and destination influences the amount of usage of the airport. The magnitude of this effect will vary with each user and each usage depending on the importance of the flight and the competing factors such as time or alternate methods of travel. It must be assumed that if a flight is not made because of an added expenditure for travel time and

distance of $1 or $2, the flight is of little economic importance to the user and, correspondingly, to the community or general economy. Such losses in airport usage must be reflected in income to the airport, but secondary losses will be negligible.

The location of the nearest airport having proper facilities affects the cost of ground transportation to the user. This can be estimated on a time and distance basis for each trip to and from the airport. Using reasonable estimates, it is possible to make benefit cost studies to obtain the optimum number and location of general-aviation airports. The loss in usage would be reflected in a reduction in the number of aircraft and the number of hours the remaining aircraft are used.

To compare the savings to users in travel time and distance with the cost of providing additional airports, alternate plans must be developed and evaluated. As a device for comparing effectiveness in developing potential, the sum of time in minutes and distance in miles has been used. The term "distance/time reference" is used to describe this sum.

Travel distance by automobile, which is the most commonly used vehicle, costs between five and ten cents per mile, depending on whether the full cost is charged or only the direct cost for additional mileage. There are logical reasons for using each figure for specific conditions. Time at a straight salary basis of $6000 per year equals about five cents per minute during working hours and a $12,000 salary would equal ten cents per minute. There is reason to assume that many trips are taken in leisure time, which would have a much reduced rate.

This analysis indicates that the travel time in minutes and travel distance in miles are probably about equal in average conditions with values of five to ten cents per unit. In this study a value of seven cents is used as a reasonable average. This would indicate that the value of each unit (mile or minute) is equal and the distance/time reference multiplied by 0.07 would equal the cost in dollars of a one-way trip by the customer to the study site.

If airports were arranged in a symmetrical pattern in an infinite area of uniform potential, the number of airports would vary inversely as the square of the average travel distance. An average travel distance of 5 miles would require four times as many airports as an average travel distance of 10 miles. In such a case, with a fixed cost of facilities and a known annual demand, there would be an optimum spacing of airports. If the cost of facilities were reduced the optimum number of airports would be greater. Correspondingly, a reduction in the demand per square mile would cause a

reduction in the optimum number of airports. This indicates that the proper spacing of airports is not fixed, such as 10 miles or 30 minutes, but is a matter for solution based on the particular conditions at a community.

Although each community will have many unique and irregular conditions, it may be well to examine a simple hypothetical situation to show the theory and method of analysis. Assume a town with four corridors of heavy commercial and residential districts--North, South, East, and West--extending outward 2 miles wide and 2 miles long around main highways that cross in the center of a business district 2 miles square (Figure 8-1). The central business district is assumed to have a potential of 100 aircraft and each of the four corridors a potential of 50 aircraft with a one-way trip to or from the airport per day for each aircraft. Sites are available on each main highway 2 miles from the edge of town or 5 miles from the center. The annual cost of each airport is $30,000 plus $120 for each based aircraft. Using seven cents per trip mile and an average speed of 40 mph outside the city, 30 mph in the corridors, and 20 mph in the central business district, and seven cents per minute for trip time, the annual cost of travel plus airport can be computed for one, two, or four airports. These assumptions give the following annual costs (in thousands of dollars) of travel and airport with 300 aircraft:

Number of Airports	Airport Costs	Travel Costs	Total Costs
1	66	145	211
2	96	112	208
4	156	86	242

Assuming such towns of the same patterns and density of aircraft with size scaled up and down to have total aircraft ownership of 150, 600, and 900 the following tabulated costs are obtained (in thousands of dollars):

Number of Airports	Airport Costs	Travel Costs	Total Costs
	150 aircraft		
1	48	53	101
2	78	40	118
4	138	31	169

Number of Airports	Airport Costs	Travel Costs	Total Costs
	600 aircraft		
1	102	406	508
2	132	314	446
4	192	240	432
	900 aircraft		
1	138	755	893
2	168	585	753
4	228	447	675

By plotting these points on a chart (Figure 8-2), we can see the number of aircraft, with corresponding town size, most economically served by one, two, or four airports. It is obvious that variations in airport costs, aircraft ownership, density, and distribution would change these figures and make it necessary to have an individual analysis for each community based on the pertinent data as forecasted.

A. AIRPORT COSTS

Development costs for an airport depend on the size of the site, the cost per acre of land, the extent of facilities, and the cost per square yard for site improvement and paving. Using current criteria, layouts have been made for small airports with sufficient size to accommodate various numbers of based aircraft. By computing the areas required and assuming various unit costs for the components, the total costs for such airports have been determined. It is obvious that the wide range possible in the cost of land per acre has a very great influence on the total capital cost. To divide capital improvement costs into annual charges, consideration must be given to the life of the improvement. Since the land does not deteriorate or become obsolete, the cost does not need to be amortized. Only the interest on the investment and, perhaps, the cost or loss of taxes need be included. This may be estimated as 5 percent of the cost as an average figure.

Since obsolescence may nullify the value of site improvements such as clearing, grading, drainage, and turfing, a useful life of about 25 years gives an annual cost of about 10 percent of the capital expenditure. Pavements and lighting systems have a shorter physical life and should be amortized over a shorter period with an annual cost of about 12 percent for paving and 16 percent for lighting. Using these figures we can arrive at annual costs for capital improvements.

Operating and maintenance costs will depend on the size of the facilities and the volume of traffic. Estimating annual costs for these items and adding to the annual costs for capital improvements gives total airport costs for various sizes of airports (Figure 8-3).

B. AIRPORT INCOME

The income of any airport depends on the amount of activity and the rate of charges. At a typical general-aviation airport, most of the income is obtained from the owners and users of based aircraft. This means that most aircraft owners spend more money for airport services at the home base than at all other airports visited as transients.

Revenue from general-aviation aircraft is obtained from the following sources:

1. Basic use or monthly tie-down charge,
2. Hangar rental (which should be separated from charge for item 1),
3. Fuel income (net to airport),
4. Commercial flight income to airport (instruction, charter, air taxi, etc.),
5. Transient aircraft, landing fees, tie-down, storage, etc.,
6. Aircraft maintenance and sales (net income to airport).

Except for item 1, the airport will normally receive only a portion of the net income. Table 8-I shows some figures that approximate the income that may be obtained from single-engine and light, twin-engine aircraft usually accommodated by general-aviation airports.

For 100 based aircraft with 50 percent in hangars and 10 percent twin-engine aircraft, the annual aircraft income would be $49,080.

It is likely that the transient aircraft will not be directly proportioned to the based aircraft since some of such traffic would be attracted by the location rather than the activity of the airport. In the example shown, itinerants account for about 30 percent of the income. Analysis of activity indicates that the range might go as low as 10 percent and sometimes exceed 50 percent.

TABLE 8-I

AIRPORT INCOME DOLLARS PER BASED AIRCRAFT PER MONTH

	Single Engine		Twin Engine	
1. Basic charge (tie down)	15		25	
To airport - 100 percent		15		25
2. Hangar rental	30		40	
To airport - 20 percent		6		8
3. Fuel (net income)	12		30	
To airport - 50 percent		6		15
4. Commercial flight	10		25	
To airport - 20 percent		2		5
5. Transient aircraft	20		50	
To airport - 50 percent		10		25
6. Maintenance and sales	10		20	
To airport - 10 percent		1		2
Total per hangared aircraft	40		80	
Total per tie-down aircraft	34		72	

Estimating a minimum annual income of $10,000 from transient aircraft and a maximum of $20,000 with 250 based aircraft, Figure 8-4 shows the range of income for the hypothetical airport. The actual costs and income with a specific number of based aircraft will be different for each individual airport. This will depend on the cost of land, improvements, and operations as well as the size and activity of the aircraft accommodated. However, the trend will be the same. For any specific location there is a number of aircraft that represents the "break even" point (Figure 8-5). In practice this may be modified somewhat by higher charges and lesser services with a reduced patronage or a corresponding improvement in services and reduction in rates when the aircraft usage increases.

When an airport is subsequently abandoned to other land usage, the investment in land may not be a cost but actually represent a capital gain income. In rapidly growing suburban areas this may permit short-term operation of marginal, privately owned airports.

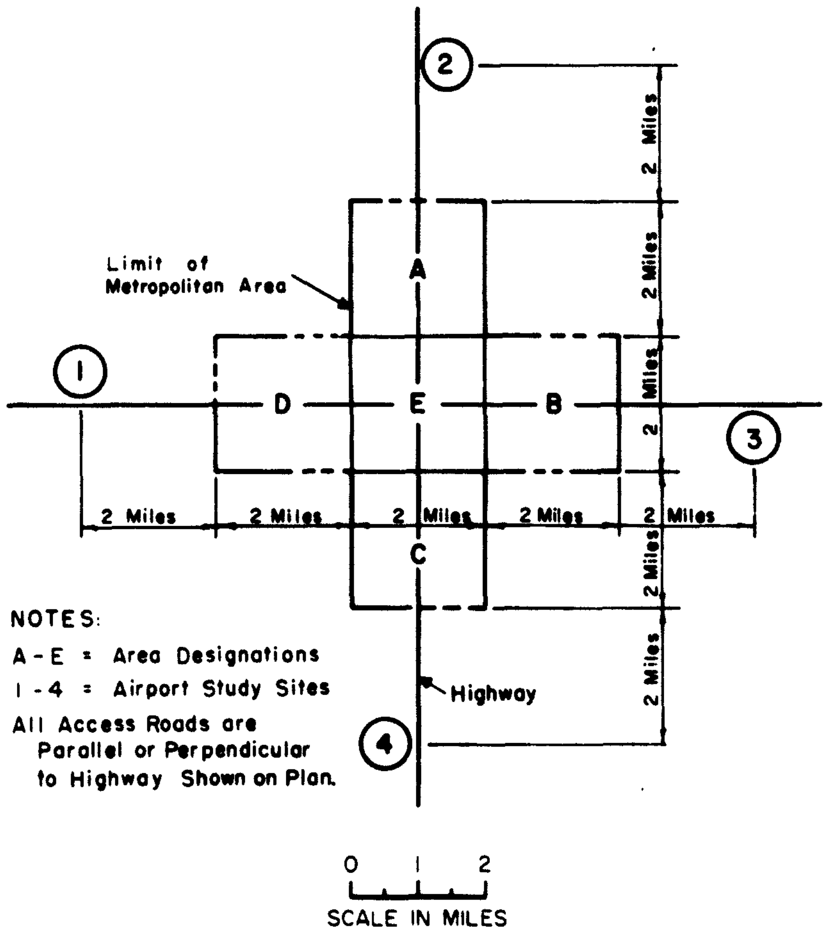


FIGURE 8-1. COSTS OF TRAVEL TO AIRPORT

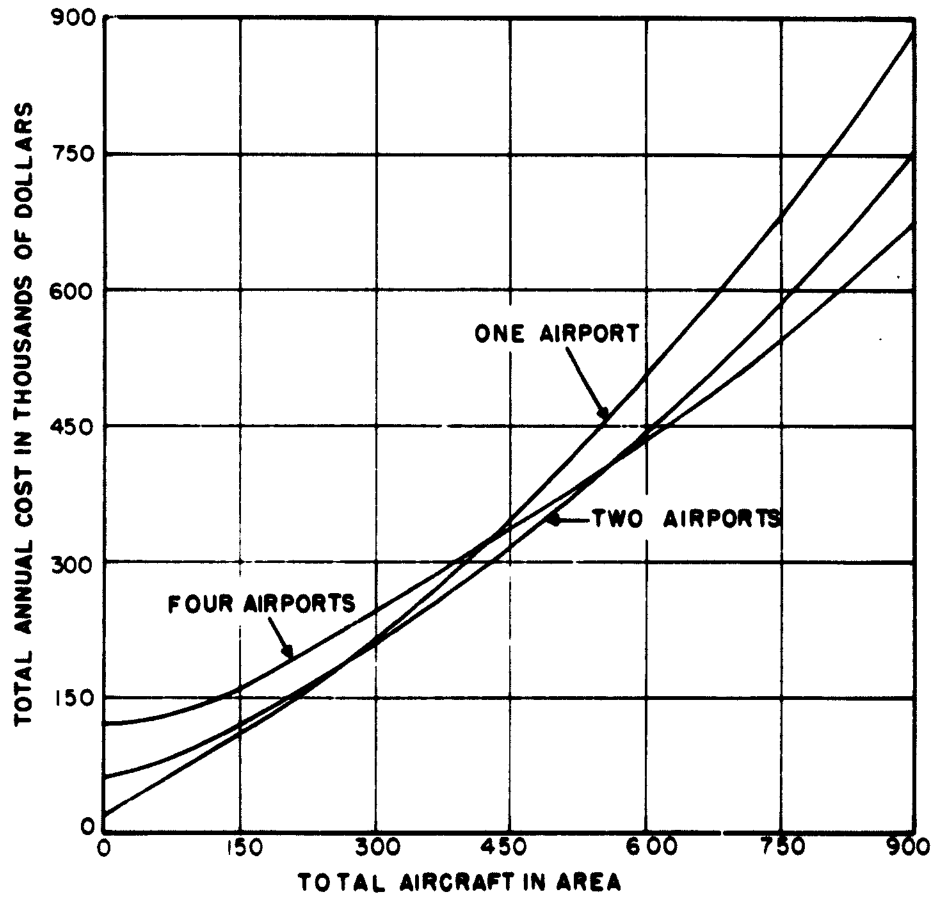


FIGURE 8-2. TRAVEL AND AIRPORT COSTS

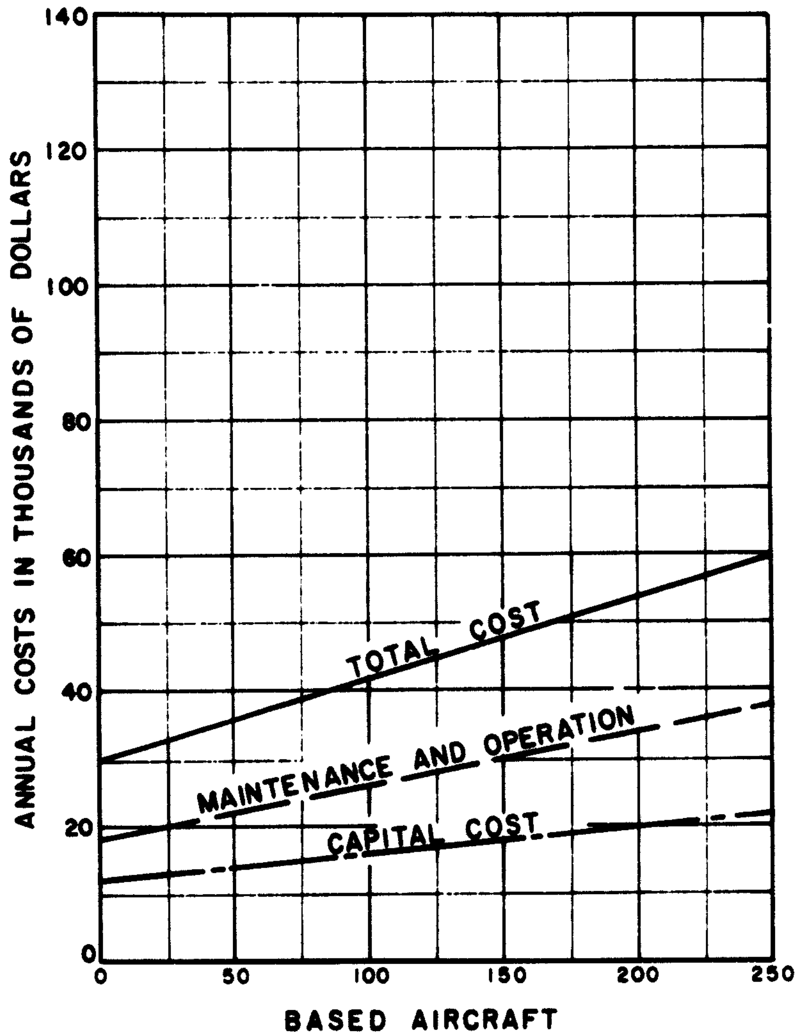


FIGURE 8-3. AIRPORT COSTS

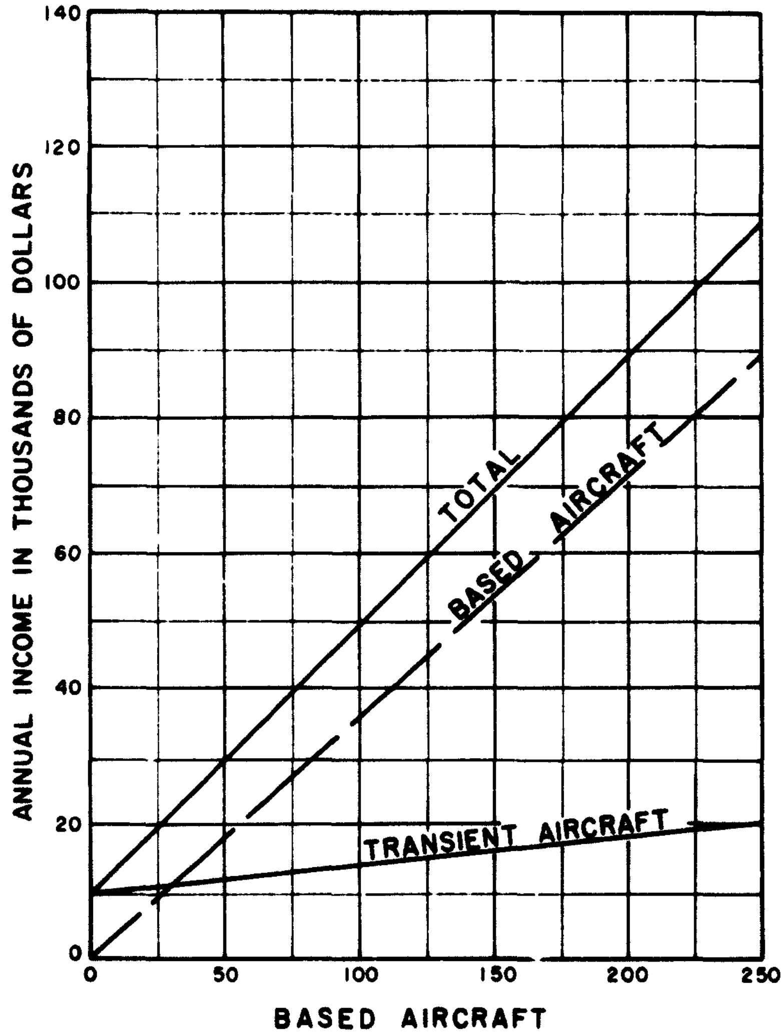


FIGURE 8-4. AIRPORT INCOME

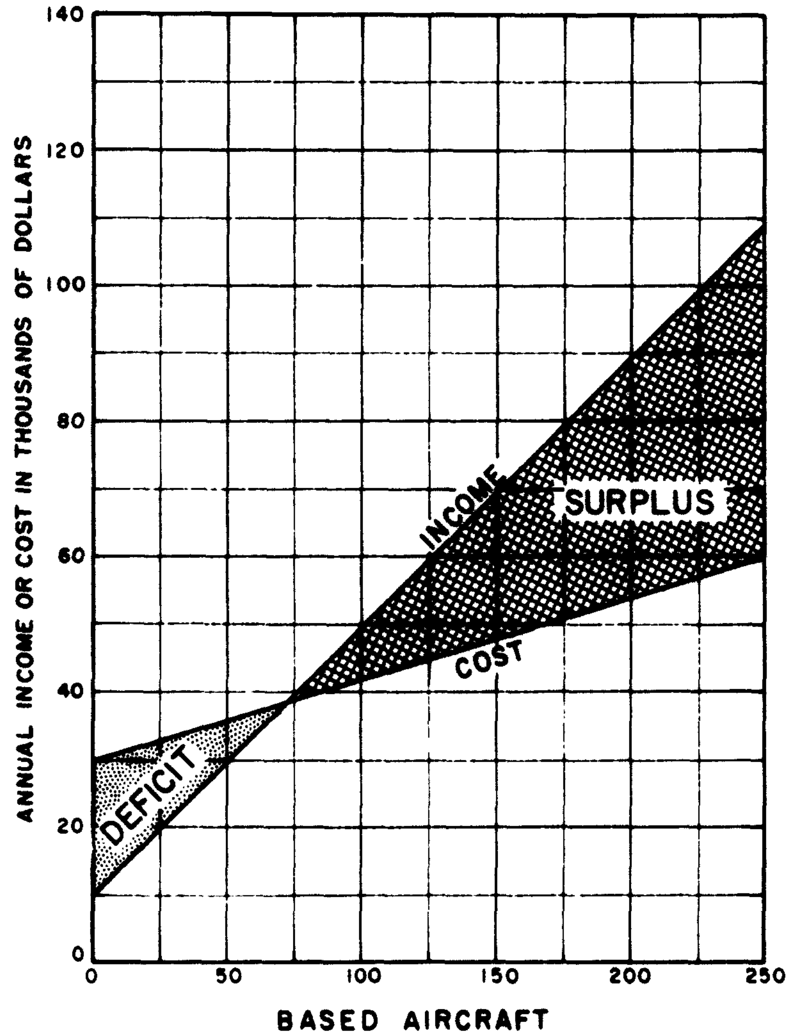


FIGURE 8-5. AIRPORT INCOME VS COST

IX. POTENTIAL GENERAL-AVIATION AIR TRAFFIC

The criteria developed in this study were used to develop a regional plan for airports in the Washington, D.C., area. The FAA realized that certain data was lacking that was important in forecasting general-aviation activity in this area. This data involved determining the relationship between aircraft ownership and airport accessibility. Preparatory to this determination, it is necessary to determine the degree to which aircraft ownership is related to personal income since this would then provide a basis for forecasting the geographic location of aircraft owners.

A criteria or procedure has been devised whereby one can predict the based aircraft that will result at various combinations of airport sites. Because this procedure has application in similar studies for other areas, it is included herein as an Appendix. The procedures involved are discussed and then illustrated by the working out of these procedures in the Washington, D.C., area. This phase of the work was performed by Landrum & Brown, Cincinnati, Ohio, as part of the team effort in the Washington, D.C., area study.

X. REFERENCES

1. F. B. Pogust and M. A. Warskow, "A New Major Airport New York/New Jersey," AIL, Deer Park, New York, Report No. 8076-1, Volumes 1 and 2, June 1960.

2. G. B. Litchford, F. B. Pogust, J. S. Perry, and R. C. Wheeler, Jr. of AIL, "National Requirements for Aviation Facilities: 1956-75," U. S. Government Printing Office, Washington 25, D. C., Volume II, "Air Traffic," May 1957.

3. "Aviation Facilities Plan for Washington," D. C. Area, AIL Report 1400-2, November, 1962.

4. Federal Aviation Agency, Bureau of Facilities and Materiel, Airports Division, "Economic Planning for General Aviation Airports," Planning Series--Item No. 4, U. S. Government Printing Office, Washington 25, D. C., December 1960.

5. Airports Service, Federal Aviation Agency, "National Airport Plan--Fiscal Years 1963-1967," U. S. Government Printing Office, Washington 25, D. C., April 1962.

6. Airports Service, Federal Aviation Agency, "Federal-Aid Airport Program: Policies and Programming Standards," U. S. Government Printing Office, Washington 25, D. C., April 1962.

7. Federal Aviation Agency, Airport Engineering Branch, Bureau of Facilities and Materiel, "Airport Design," U. S. Government Printing Office, Washington 25, D. C., 1961.

8. Federal Aviation Agency, "Statistical Study of U. S. Civil Aircraft as of January 1961," U. S. Government Printing Office, Washington 25, D. C., July 1961.

9. Aviation Week and Space Technology, McGraw-Hill Publishing Company, Inc., New York. Various articles on civil aircraft have appeared throughout the past few years.

10. Business/Commercial Aviation Magazine, Conover-Mast Publications, Inc., New York. Various articles on civil aircraft have appeared throughout the past few years.

11. W. Greene and G. Pollinger, "The Aircraft of the World," Macdonald and Co., Publishers, Limited, London, England, Great Britain, 1956.

12. L. Bridgman, editor, "Jane's All the World's Aircraft," McGraw-Hill Book Company, Inc., New York, 1956-57.

13. Federal Aviation Agency, "Small Airports," U. S. Government Printing Office, Washington 25, D. C., January 1959.

14. W. E. Gillfillan, "Airplane Performance and the Small Airport," Reprint from Journal of the Air Transport Division, Proceedings of the American Society of Civil Engineers, March 1961.

15. "A Report on Runway Characteristics and Performance of Selected Propeller-Driven Aircraft in Routine Operation," AIL Report No. 5791-15, Volume III, April 1960.

16. Air Traffic Service, Federal Aviation Agency, "Air Traffic Control Procedures," ATP 7110.1A, U. S. Government Printing Office, Washington, 25, D. C., 1 July 1962.

17. Federal Aviation Agency, "Regulations of the Administrator, Part 550. Federal Aid to Public Agencies for Development of Public Airports," U. S. Government Printing Offic, Washington 25, D. C., 18 November 1960.

18. M. A. Warskow, et al., "Airport Runway and Taxiway Design," AIL Report No. 7601-1, July 1960.

19. Federal Aviation Agency, "FAA Air Traffic Activity--Fiscal Year 1961," U. S. Government Printing Office, Washington 25, D. C., August 1961.

20. Landrum and Brown and AIL, "Chicago-O'Hare International Airport--Analysis of Capacity and Master Plan," Commissioner of Aviation, City of Chicago, Illinois, April 1962.

21. Bureau of Air Traffic Management, "Terminal Area Air Traffic Relationships," Federal Aviation Agency, Washington 25, D. C., 1960.

22. AOPO Foundation, Inc., "General Aviation Aircraft Operations," Washington 14, D. C., 1961.

23. W. E. Gillfillan, "California General Aviation: Airports, Aircraft, and Flight Activity," Special Study by Institute of Transportation and Traffic Engineering, University of California, Berkely, June 1961.

24. Systems Engineering Team of Office of Aviation Facilities Planning, The White House, "Modernizing the National System of Aviation Facilities," U. S. Government Printing Office, Washington 25, D. C., May 1957.

25. Test and Experimentation Division, Aviation Research and Development Service, Federal Aviation Agency, "Evaluation of Parallel Runway Spacing," Task No. 412-3-2T, U. S. Department of Commerce, Washington 25, D. C., July 1961.

26. "Airport Capacity," A Handbook for Analyzing Airport Designs to Determine Practical Movement Rates and Aircraft Operating Costs, AIL Report 7601-H-2 to be published in June, 1963.

27. Federal Aviation Agency, "Regulations of the Administrator, Part 625 Landing Area, Notice of Proposed Establishment, Alteration, or Deactivation," U. S. Government Printing Office, Washington 25, D. C., 15 November 1961.

28. Federal Aviation Agency, "Airway Planning Standard Number 4. Leased Communication Services," Washington 25, D. C., January 1962.

29. Federal Aviation Agency, "Airway Planning Standard Number 3. Air Traffic Communication Services," Washington 25, D. C., March 1960.

30. Federal Aviation Agency, "Airway Planning Standard Number 1. Airport Traffic Control and Terminal Navigational Aids," Washington 25, D. C., May 1960.

31. United States Army, Navy, Air Force, Coast Guard, and Civil Aeronautics Administration, "United States Manual of Criteria for Standard Instrument Approach Procedures," U. S. Government Printing Office, Washington 25, D. C., Third Edition, 1 September 1956.

APPENDIX

DETERMINATION OF POTENTIAL GENERAL AVIATION AIR TRAFFIC

December, 1962

Landrum & Brown

Cincinnati, Ohio

TABLE OF CONTENTS

	Page
I PURPOSE	1
II DETERMINE THE FORECASTS OF POTENTIAL GENERAL AVIATION DEMAND	2
A. Define the Study Area.	2
B. Determine the Study Area's economic profile and its relationship to general aviation.	2
C. Determine the historic patterns of general aviation in the Study Area related to the state, region and the total United States.	2
D. Determine reasonable forecast volumes of Potential General Aviation Demand, as measured in terms of the number of active civil based aircraft.	3
1. Example of application to Washington Area Study	
Objective	4
Findings	5
Criteria	7
III DETERMINE THE DISTRIBUTION OF POTENTIAL GENERAL AVIATION DEMAND	11
A. Determine for the latest available and forecast periods desired population and income information.	11
B. Determine the existing or present location, by specific census tract, or other area, of the owners of the active general aviation aircraft within the study area.	12
C. Determine the relationship, if any, between the personal economic characteristics of general aviation aircraft owners and their propensity to own general aviation aircraft.	12

Page

1. Example of Application to Washington Study Area

Objective 14

Findings 15

Criteria 17

D. Determine the distribution of the potential general aviation demand giving consideration to the relative propensity to own general aviation aircraft by income class. 18

1. Example of Application to Washington Study Area

Objective 19

Findings 20

Criteria 28

IV. DETERMINE THE POTENTIAL GENERAL AVIATION DEMAND THAT MAY BE EXPECTED TO BE REALIZED AT SELECTED AIRPORT SITES OR AREAS 31

A. Determine on the basis of actual survey, or other appropriate methods, whether accessibility has an effect upon the utilization of general aviation airports. 31

B. Determine the degree of effect, if any, that accessibility has upon the utilization of general aviation airports within the study area. 31

1. Example of Application to Washington Study Area

Objective 32A

Findings 33

Criteria 34

C. Determine the forecasts of realized potential general aviation demand, by selected airport sites or areas that may be expected, giving consideration to the effect of airport accessibility on the forecast distribution of potential general aviation demand within the study area. 39

	Page
1. Example of Application to Washington Study Area	
Objective	40
Findings	41
Criteria	42

I PURPOSE

This paper describes a procedure for preparing qualified studies of potential general aviation air traffic that would be realized at alternate sites or areas. The procedure divides into three major steps:

Determining Forecasts of Potential General Aviation Demand for the study area;

Determining the Distribution of the Forecast Demand within the study area; and

Determining the Forecast Demand that may be realized at selected airport sites.

The procedures to be followed in accomplishing these steps are described. They are then illustrated by presenting their application to the Washington Study Area.

II DETERMINE THE FORECASTS OF POTENTIAL GENERAL AVIATION DEMAND

The following steps may be considered essential to a determination of the forecasts of potential general aviation demand.

A. Define the study area – depending upon the economic character, composition and size of a given community and the relative location of general aviation airports therein, determine an appropriate method for definition of the area to be studied. For example, a Standard Metropolitan Statistical Area – as defined by the Bureau of the Census delineating the counties and/or independent cities located therein – may be considered most appropriate.

B. Determine the study area's economic profile and its relationship to general aviation – this information should properly include a review and analysis of the major indicators of economic activity for an historic period (most recent ten years, for example) such as:

1. population
2. income
3. distribution of employment
4. manufacturing employment, by major industry group
5. value added by manufacture, by industry group
6. wholesale and retail sales activity

These economic indicators should then be examined on a comparative basis with the historic patterns of general aviation activity within the study area (See II C).

C. Determine the historic patterns of general aviation in the study area related to the state, region and the total United States – this information should properly consist

of a review and analysis of the historic growth of the number of active civil based aircraft engaged in general aviation activity at all public and privately owned airports within the previously defined study area. This information, when compiled, should be related to the growth patterns exhibited within the state, region and the total United States to provide a reasonable assessment of the historic growth between the study area and these other regions. Additionally, the growth patterns of general aviation active civil based aircraft in the study arec should be compared to the various economic indices, for a comparable period, to determine whether general aviation is growing at the same, faster or lesser rate than the economy of the area. (See II-B).

D. Determine reasonable forecast volumes of Potential General Aviation Demand, as measured in terms of the number of active civil based aircraft – this final determination of the potential general aviation demand for the study area should properly consist of the previously discussed items, namely:

1. the economic profile
2. the number of active civil based aircraft
3. the comparison of growth patterns within the study area, that is:
    a. between theeconomy and general aviation in the area
    b. between general aviation activity in the area and the state, region and total United States

and a review and analysis of all available forecast information published by the various Federal, State and Local government agencies, concerning general aviation activity. For illustration purposes, the following example for the Washington Study Area, indicates the forecast of potential general aviation demand for 1970 and 1980.

OBJECTIVE

Determine the total potential demand for general aviation in the Washington Study Area, in terms of the number of based aircraft for 1970 and 1980. This data will indicate the size of the potential market to be accommodated at general aviation airports and will provide the data necessary for indicating the distribution of this market in the area.

FINDINGS

The forecast of the potential general aviation demand, in terms of the number of based aircraft, is presented below for the Washington Study Area.

FORECAST: NUMBER OF BASED AIRCRAFT — TABLE I

BY TYPE OF AIRCRAFT — Page 1 of 2

UNCONTROLLED AND CONTROLLED AIRPORTS – WASHINGTON STUDY AREA

1962, 1970 AND 1980

Period (1)	Total Based Aircraft (2)	Multi-Engine (3)	Single Engine 4 Place or More (4)	Other (5)
1962 –				
Uncontrolled	666	27	346	293
Controlled	153	51	33	69
Total	819	78	379	362
1970 –				
Uncontrolled	866	46	520	300
Controlled	199	84	44	71
Total	1,065	130	564	371
1980 –				
Uncontrolled	1,119	82	772	265
Controlled	257	138	57	62
Total	1,376	220	829	327

TABLE I

Source: Columns (1) and (2) – Actual – Records of the respective uncontrolled and controlled airports.
Forecast – All Uncontrolled Airports and for each Controlled Airport – Extension into each of the periods based on index of the forecasts of total United States Aircraft Fleet: 1962 = 100, 1970 = 130, 1980 = 168.

(3), (4) and (5) – Actual – Records of the respective uncontrolled and controlled airports.
Forecast - All Uncontrolled Airports and for each Controlled Airport – Extension of each type of aircraft an index of the total United States Aircraft Fleet:

	Multi Engine	Single Engine 4 Place or More	Others
1962	100	100	100
1970	171	148	101
1980	293	214	87

CRITERIA

1. The number of active civil based aircraft – in total and by type of equipment at thirteen uncontrolled airports, in 1962, is shown on Table II.

2. The number of active civil based aircraft – in total and by type of equipment at two controlled airports, in 1962, is presented on Table III.

3. The actual and forecast number of active civil based aircraft for the United States – in total and by type of equipment are noted on Table IV. These forecasts were used as the basis for extending the forecasts for the uncontrolled and controlled airports, from 1962 to 1970 and 1980, for the Washington Study Area.

NUMBER OF ACTIVE CIVIL BASED AIRCRAFT

TABLE II

UNCONTROLLED AIRPORTS

WASHINGTON STUDY AREA

1962

Airport (1)	Total Based Aircraft (2)	Multi-Engine (3)	Single Engine 4 Place or More (4)	Other (5)
Maryland	24	0	9	15
Rose Valley	47	0	17	30
Davis	28	0	8	20
Leesburg	21	1	10	10
Rutherford	52	2	39	11
Frederick	41	6	24	11
Suburban	35	0	20	15
Washington-Va.	130	5	60	65
College Park	37	1	17	19
Lee	22	0	0	22
Montgomery Co.	106	9	91	6
Hyde Field	75	3	35	37
Manassas	48	0	16	32
Total	666	27	346	293
Per cent of Total	100.0%	4.0%	52.0%	44.0%

Source: All Columns – Records of the respective uncontrolled airports.

NUMBER OF ACTIVE CIVIL BASED AIRCRAFT

TABLE III

CONTROLLED AIRPORTS

WASHINGTON STUDY AREA

1962

Airport (1)	Total Based Aircraft (2)	Multi-Engine (3)	Single Engine 4 Place or More (4)	Other (5)
Washington National	44	18	23	3
Baltimore Friendship	109	33	10	66

Source: All Columns – Records of the respective controlled airports.

ACTUAL AND FORECAST – TOTAL UNITED STATES

TABLE IV

GENERAL AVIATION AIRCRAFT BY TYPE OF EQUIPMENT

1960 – 1961 ACTUAL – 1962, 1970 AND 1980 FORECAST

		Multi-Engine		Single-Engine			
				4 Place or More		Other	
Year (1)	Total (2)	Number (3)	% of Total (4)	Number (5)	% of Total (6)	Number (7)	% of Total (8)
Actual							
1960	68,727	6,034	9%	27,301	40%	35,392	51%
1961	76,549	7,243	9	34,327	45	34,979	46
Forecast							
1962	80,500	8,200	10%	37,800	47%	34,500	43%
1970	105,000	14,000	13	56,000	54	35,000	33
1980	135,000	24,000	18	81,000	60	30,000	22

Source: Columns (1), (2), (3), (5) and (7) – Actual – Aviation Forecasts, Fiscal Years 1962-1967, Federal Aviation Agency, Table 6.
Forecast – 1962 Aviation Forecasts, Fiscal Year; Federal Aviation Agency, Table 6.
1970 Forecast prepared for Project Horizon.
1980 – Extension of forecasts based on same rate of growth forecast between 1970 - 1975.

(4), (6) and (8) – Percent each respective preceding Column is of the total in Column (2).

III DETERMINE THE DISTRIBUTION OF THE POTENTIAL GENERAL AVIATION DEMAND

Having previously determined the forecasts of potential general aviation demand for the study area, it is then important to determine the distribution of this demand. This may be accomplished in the following manner:

A. Determine for the latest available and forecast periods desired (minimum - 10 to maximum — 25 years) population and income information – the historic information is generally available through Government agencies for areas such as:

1. standard metropolitan statistical areas
2. counties
3. incorporated places
4. unincorporated places
5. independent cities
6. census tracts

Information requisite to the tracted or similarly defined areas for the above groupings may be expected to indicate, among other things:

1. population
2. median family income
3. median income of families and unrelated individuals
4. number of families in various income groupings

For cross-referencing purposes, it is desirable to obtain maps and street indices for the study area, if available. Planning commissions or groups of the respective areas, such as a county, often compile this information subsequent to a decennial census by the Federal

Government, such as in 1960.

It is highly desirable that forecast information concerning population and income, be available in similar detail, for the same study area.

B. Determine the existing or present location, by specific census tract or other areas, of the owners of the active general aviation aircraft within the study area – this information may be obtained by three methods:

1. existing studies and records of airports with general aviation aircraft based thereon

2. current records of general aviation aircraft compiled by various groups or organizations

3. survey of the aircraft owners within the study area

C. Determine the relationship, if any, between the personal economic characteristics of general aviation aircraft owners and their propensity to own general aviation aircraft – this relationship consists of an examination of the following inter-related elements of:

1. population and income data – historic and forecast
2. general aviation aircraft owners

This analysis should serve to indicate the number of aircraft owners located within specific census tracts or other areas and the total population within specified income groupings by tracts or areas. Having this information compiled, it is possible to determine the relative propensity to own general aviation aircraft by relating the aforementioned aircraft owners to a measure of population (e.g. owners/10,000 population basis), by the

selected income groupings. The relative likelihood of owning an aircraft is computed, therefore, by relating the number of aircraft owners per selected measure of population, by income class, to the average number of aircraft owners per selected measure of population. For illustration purposes, the following example for the Washington Study Area, indicates, in part, the method employed to determine the forecast distribution of potential general aviation demand as relates to the indicated propensity to own general aviation aircraft.

OBJECTIVE

Determine the relationship, if any, between the personal economic characteristics of aircraft owners and/or users and their propensity to own or use general aviation aircraft. This relationship, if it exists, will serve to indicate the relative distribution of the potential market to be accommodated at general aviation airports, giving proper consideration to population and income characteristics within the area, during the forecast period.

FINDINGS

Table V below, shows the relationship of population, income classes and their propensity to own or use general aviation aricraft.

The table indicates that the higher the income class (class 1 is the lowest, class 5 is the highest) of the population the more aircraft owners and/or users per 10,000 units population.

It should be noted that similar studies for air passengers have shown similar results that is, the higher the family income, the greater the likelihood to use air transportation for making trips.

DISTRIBUTION OF 1960 POPULATION AND 1962 AIRCRAFT OWNERS BY TRANSPORTATION SURVEY INCOME CLASSES WASHINGTON STUDY AREA

TABLE V
Page 1 of 2

Income Class (1)	1960 Population (2)	1962 Aircraft Owners and/or Users: Number (3)	% of Total (4)	Per 10,000 Population (5)	Population Index (6)
1	108,885	2	1%	.18	.18
2	617,122	34	17	.55	.55
3	899,652	99	50	1.10	1.10
4	331,773	56	28	1.69	1.69
5	31,166	8	4	2.57	2.57
Total or Average	1,988,598*	199	100%	1.00	1.00

*Total of the Washington Standard Metropolitan Statistical Area is 2,001,897; the difference represents duplication in Census Counts and elements unable to identify totaling 13,299.

TABLE V

Page 2 of 2

Source: Column (1) - Income Classes per "Projection to 1980 of Selected Residential and Economic Statistics, By Transportation District and Statistical Area, For Cities and Counties In The National Capital Region" MTS-27, February 11, 1957.

(2) - 1960 Census Tract Populations.

(3) - Surveyed By Landrum and Brown.

(4) - Column (3) % to total.

(5) - Column (2) divided by Column (3).

(6) - Index of Column (5) - Average = 100.

CRITERIA

The following is the technique used for determining the relationship between the personal economic characteristics of general aviation aircraft owners and their propensity to own general aviation aircraft. The step by step determination is as follows:

1. The 1960 census population and aircraft owners and users surveyed in August and September 1962, by Census tract, were converted to correspond to the transportation survey districts and statistical areas established by the Mass Transportation Survey Staff for cities and counties in the National Capital Region.

2. The 1960 population and the 1962 aircraft owners surveyed (199) were then combined in total according to 1980 income classes established by the Mass Transportation Staff for the survey districts and statistical areas. (It was felt reasonable to assume that the relationship between 1980 income classes, established by the Mass Transportation Survey Staff, would also exist between 1970 income classes. That is, the dollar value of the income classes in 1970 may be less than in 1980, but the <u>relationship between income classes</u> would remain the same. Also the income class assigned to the individual districts and areas would remain the same.) Columns (2) and (3) of Table V shows the distribution of 1960 population and 1962 aircraft owners and/or users surveyed by income class.

3. The relative propensity to own and/or use aircraft was then determined by relating the number of aircraft owners and/or users to population on a per 10,000 population, by income class, basis. (Column (5) of Table V).

4. The next step was to determine an index of the relative likelihood to own and/or use aircraft by income class. This was determined by relating the number of aircraft owners and/or users (surveyed) per 10,000 population by income class to the average number of aircraft owners per 10,000 population. See Column (6), Table V.

5. The index of relative likelihood to own and/or use general aviation aircraft will be used in the determination of the distribution of the potential general aviation demand (see III - D).

D. Determine the distribution of the potential general aviation demand, giving consideration to the relative propensity to own general aviation aircraft, by income class - having determined the location of the general aviation aircraft owners, by census tract or other areas (see III-B) and the index of the relative likelihood to own and/or use general aviation aircraft (see III-C) and with the knowledge of the pertinent population and income data, it is possible to determine, therefore, the distribution of the potential general aviation owners and users for each census tract or other area within the study area. This distribution when converted into percentages would indicate the relative percentage distribution of potential general aviation aircraft owners, for each study unit. The application of this percentage distribution when applied to the forecast of the total potential general aviation demand (see II-D), for the study area, produces the distribution of the potential general aviation demand in terms of based aircraft. For illustration purposes, an example of the distribution of the potential general aviation demand for the Washington Study Area is shown for 1970 and 1980, indicating the methods employed in this determination.

OBJECTIVE

Determine the distribution of the potential demand for general aviation in the Washington Study Area for 1970 and 1980. This distribution will indicate the location, by survey district and statistical area, of the potential market that may be accommodated at selected airport sites or areas during the forecast period. Additionally, this distribution will give proper consideration to the effect that population and income have upon the propensity to own or use general aviation aircraft within each of the aforementioned survey districts and statistical areas.

FINDING

The population and income class for 1980, the relative distribution of aircraft owners in 1970 and 1980 by survey district and statistical area and the distribution of based aircraft is presented on Table VI.

1980 POPULATION, INCOME CLASS AND RELATIVE DISTRIBUTION TABLE VI
OF AIRCRAFT OWNERS (WITH WASHINGTON NATIONAL RESTRICTED) Page 1 of 7
BY SURVEY DISTRICT AND STATISTICAL AREA
WASHINGTON S.M.S.A.

Survey District or Statistical Area (1)	1980 Population (2)	Income Class (3)	Relative Percentage Distribution of Aircraft (4)	Distribution of Based Aircraft 1970 (5)	1980 (6)
District of Columbia					
01	12,200	2	.21%	1.70	2.19
02	-	-	-	-	-
03	10,500	2	.20	1.62	2.09
04	23,500	1	.14	1.13	1.46
05	1,000	2	.02	.16	.21
06	39,000	1	.24	1.94	2.51
07	6,000	2	.11	.89	1.15
08	28,500	2	.54	4.37	5.64
09	8,200	3	.31	2.51	3.24
11	35,000	3	1.32	10.68	13.79
12	13,000	4	.75	6.07	7.84
13	10,000	5	.88	7.12	9.20
22	22,000	3	.83	6.71	8.67
23	22,500	4	1.30	10.52	13.58
24	15,000	4	.87	7.04	9.09
25	15,600	5	1.38	11.16	14.42
31	9,500	3	.35	2.83	3.66
32	73,000	1	.45	3.64	4.70
33	52,500	2	.99	8.01	10.35
34	43,500	2	.82	6.63	8.57

TABLE VI

Survey District or Statistical Area (1)	1980 Population (2)	Income Class (3)	Relative Percentage Distribution of Aircraft (4)	Distribution of Based Aircraft 1970 (5)	1980 (6)
District of Columbia Cont'd.					
35	40,500	3	1.53	12.38	15.99
41	38,800	1	.24	1.94	2.51
42	14,500	2	.27	2.18	2.82
43	44,000	3	1.66	13.43	17.35
44	16,000	2	.30	2.43	3.14
51	40,500	2	.77	6.23	8.05
52	62,500	2	1.18	9.55	12,33
53	40,200	2	.76	6.15	7.94
61	16,300	3	.61	4.93	6.37
62	34,200	2	.65	5.26	6.79
63	61,700	3	2.33	18.85	24.35
64	90,300	2	1.71	13.83	17.87
Total	940,000	-	23,72	191.89	247.87
Montgomery County					
16	17,000	4	.97	7.85	10.13
17	15,700	4	.91	7.36	9.51
26	21,300	4	1.24	10.03	12.96
27	18,600	5	1.64	13.27	17.14
28	34,300	4	1.99	16.10	20.79
29	85,300	3	3.22	26.05	33.65
36	31,600	4	1.83	14.81	19.12
37	19,000	3	.72	5.82	7.52
38	33,200	3	1.25	10.11	13.06
101	8,500	4	.49	3.96	5.12

TABLE VI

Survey District or Statistical Area (1)	1980 Population (2)	Income Class (3)	Relative Percentage Distribution of Aircraft (4)	Distribution of Based Aircraft 1970 (5)	Distribution of Based Aircraft 1980 (6)
Montgomery County Cont'd.					
102	13,200	4	.77	6.23	8.05
103	13,300	3	.50	4.05	5.22
104	5,800	2	.11	.89	1.15
105	8,200	2	.15	1.21	1.57
201	17,400	3	.66	5.34	6.90
202	11,000	3	.42	3.40	4.39
203	22,000	4	1.28	10.36	13.38
204	24,500	3	.93	7.52	9.72
205	8,800	3	.33	2.67	3.45
206	4,000	2	.08	.65	.84
207	19,000	3	.72	5.82	7.52
208	11,200	3	.42	3.40	4.39
209	11,000	2	.21	1.70	2.19
210	11,800	3	.45	3.64	4.70
211	8,000	2	.15	1.21	1.57
212	13,000	3	.49	3.96	5.12
213	14,000	2	.26	2.10	2.72
214	10,500	3	.40	3.24	4.18
301	7,500	4	.44	3.56	4.60
302	12,800	4	.74	5.99	7.73
303	28,500	3	1.08	8.74	11.29
Total	560,000	-	24.85	201.04	259.68

TABLE VI

Survey District or Statistical Area (1)	1980 Population (2)	Income Class (3)	Relative Percentage Distribution of Aircraft (4)	Distribution of Based Aircraft 1970 (5)	Distribution of Based Aircraft 1980 (6)
Prince Georges County					
37	18,000	3	.67	5.42	7.00
39	19,000	3	.72	5.83	7.53
45	36,200	2	.68	5.50	7.11
46	35,100	2	.66	5.34	6.90
47	23,800	2	.45	3.64	4.70
48	35,800	3	1.35	10.92	14.11
49	27,100	3	1.02	8.25	10.66
56	31,900	2	.60	4.86	6.27
57	40,300	2	.76	6.15	7.94
66	30,400	3	1.15	9.30	12.02
67	24,300	3	.92	7.44	9.62
68	8,500	3	.32	2.59	3.34
401	7,300	4	.42	3.40	4.39
402	8,700	3	.33	2.67	3.45
403	10,500	3	.40	3.24	4.18
404	24,800	3	.94	7.61	9.82
405	-	-	-	-	-
406	11,500	2	.22	1.78	2.30
407	11,000	2	.21	1.70	2.19
408	11,500	3	.44	3.56	4.60
501	11,000	2	.21	1.70	2.19
502	9,900	2	.19	1.54	1.99
503	15,500	3	.59	4.77	6.17
504	8,200	3	.31	2.51	3.24
505	2,200	2	.04	.32	.42
506	8,000	2	.15	1.21	1.57
507	5,800	2	.11	.89	1.15
601	4,700	3	.18	1.46	1.88
602	15,300	3	.58	4.69	6.06
603	16,600	3	.63	5.10	6.58

TABLE VI

Survey District or Statistical Area (1)	1980 Population (2)	Income Class (3)	Relative Percentage Distribution of Aircraft (4)	Distribution of Based Aircraft 1970 (5)	Distribution of Based Aircraft 1980 (6)
Prince Georges County Cont'd.					
604	3,100	3	.12	.97	1.25
605	31,500	4	1.83	14.80	19.12
606	10,800	3	.41	3.32	4.28
607	14,500	3	.55	4.45	5.75
608	4,000	3	.15	1.21	1.57
609	7,500	2	.14	1.13	1.46
610	7,700	2	.14	1.13	1.46
611	1,800	2	.03	.24	.31
Total	593,800	-	18.62	150.64	194.58
Arlington County					
71	7,500	3	.27	2.19	2.82
72	20,000	3	.75	6.07	7.84
73	15,500	3	.59	4.77	6.17
74	45,000	4	2.61	21.11	27.27
81	38,000	2	.72	5.82	7.52
82	30,000	3	1.13	9.14	11.81
83	24,000	4	1.39	11.25	14.53
84	25,000	4	1.45	11.73	15.15
Total	205,000	-	8.91	72.08	93.11
Alexandria					
76	36,000	3	1.35	10.92	14.11
77	30,000	2	.57	4.61	5.95
78	44,500	3	1.68	13.59	17.56
706	11,500	3	.44	3.56	4.60
Total	122,000	-	4.04	32.68	42.22

TABLE VI

Survey District or Statistical Area (1)	1980 Population (2)	Income Class (3)	Relative Percentage Distribution of Aircraft (4)	Distribution of Based Aircraft 1970 (5)	Distribution of Based Aircraft 1980 (6)
Fairfax County and Falls Church					
75	13,000	4	.74	5.99	7.73
79	22,000	3	.83	6.72	8.67
86	32,000	3	1.21	9.79	12.64
87	24,000	4	1.39	11.25	14.52
88	25,000	4	1.45	11.73	15.15
701	14,000	3	.53	4.29	5.54
702	10,000	3	.38	3.08	3.97
703	13,000	3	.49	3.96	5.12
704	11,000	3	.42	3.40	4.39
705	23,000	3	.86	6.96	8.99
707	7,200	3	.27	2.18	2.82
708	17,000	3	.64	5.18	6.69
709	23,800	3	.90	7.28	9.41
710	11,500	3	.44	3.56	4.60
711	7,200	3	.27	2.18	2.82
712	17,000	3	.64	5.18	6.69
713	4,700	3	.18	1.46	1.88
714	9,000	3	.34	2.75	3.55
715	5,000	3	.19	1.54	1.99
716	4,000	4	.23	1.86	2.40
717	10,200	3	.38	3.07	3.97
718	5,000	3	.19	1.54	1.99
719	5,000	3	.19	1.54	1.99
720	13,500	2	.25	2.02	2.61
801	6,000	4	.35	2.83	3.66
802	17,000	4	.98	7.93	10.24
803	4,300	3	.16	1.29	1.67
804	15,500	4	.90	7.28	9.41
805	10,000	5	.88	7.12	9.20
806	15,500	3	.59	4.77	6.17

TABLE VI

Survey District or Statistical Area (1)	1980 Population (2)	Income Class (3)	Relative Percentage Distribution of Aircraft (4)	Distribution of Based Aircraft 1970 (5)	Distribution of Based Aircraft 1980 (6)
Fairfax County and Falls Church Cont'd.					
807	12,000	3	.45	3.64	4.70
808	10,000	3	.38	3.07	3.97
809	5,200	3	.20	1.62	2.09
810	6,500	3	.25	2.02	2.61
811	6,700	3	.25	2.02	2.61
812	6,800	3	.26	2.10	2.72
813	12,200	3	.46	3.72	4.81
814	6,000	2	.11	.89	1.15
815	6,000	3	.23	1.86	2.40
Total	466,800	-	19.86	160.67	207.54
Washington National (Restricted)				57.00	74.00
Distributed Number				809.00	1045.00
Total S.M.S.A.	2,887,600		100.00%	866.00	1119.00

Source: Column (1) Survey District or Statistical Area
(2) and (3) Report "Projection to 1980 of Selected Residential and Economic Statistics, By Transportation Survey Districts and Statistical Area, For Cities and Counties in the National Capital Region" by Mass Transportation Survey Staff.

(4) Percentage Distribution of relative propensity to own or use General Aviation Aircraft by Survey District and Statistical Area.
(5) and (6) Distribution of total based on Column (4).

CRITERIA

1. The survey districts and statistical areas have been established by the National Capital Regional Planning Council.

2. The population and income class information as forecast for 1980 was derived from the following report "Projection to 1980 of Selected Residential and Economic Statistics, By Transportation Survey District and Statistical Area, For Cities and Counties in the National Capital Region" by the Mass Transportation Survey Staff.

3. The population and income class information as forecast in the aforementioned report, for 1980, is considered to be a reasonable, relative distribution of the population and income classes for 1970 - lacking specific 1970 forecast information - for the Washington Study Area. Simply stated, if the relative population distribution for a given survey district as a per cent of the total area was forecast at 10.0% in 1980, it was considered reasonable that this same percentage would be applicable in 1970. The same pertains to the income class information in 1970.

4. Precedent to the determination of the relative distribution of the aircraft owners in 1980, it was necessary to determine the relative percentage distribution of aircraft owners that may be expected within each survey district and statistical area. This was accomplished in the following manner:

   a. determine on the basis of a survey of general aviation aircraft owners and users in 1962, their respective location within the

survey districts and statistical areas as established by the National Capital Regional Planning Council.

b. determine for each survey district and statistical area the pertinent population and income class information.

c. adjust the number of aircraft owners and users for each survey district and statistical area, giving consideration to the factors of population and income and their effect upon the propensity to own or use general aviation aircraft, as noted on Table V.

d. determine the relative percentage distribution of the aircraft owners and users, as adjusted, for each survey district or statistical area; this is shown on Table VI.

5. Having determined this relative percentage distribution of aircraft owners and users in 1980, adjusted for the factors of population and income it was then possible to apply these measures to the forecasts of total potential demand for general aviation, in terms of the number of based aircraft in 1980. The total number of based aircraft for 1980 represents an amount for the total Washington Study Area, less a fixed amount for Washington National Airport since it was considered reasonable to restrict general aviation activities at this airport during the forecast period.

6. Since it was determined that the relative distribution of population and income

would reasonably be considered to be the same in 1970, as forecast for 1980. the relative percentage distribution of aircraft owners and users is indicated to be the same in 1970 and 1980.

7. The forecast distribution of the potential general aviation demand in terms of based aircraft is noted on Table VI for the Washington area in 1970 and 1980.

IV DETERMINE THE POTENTIAL GENERAL AVIATION DEMAND THAT MAY BE EXPECTED TO BE REALIZED AT SELECTED AIRPORT SITES OR AREAS

With the knowledge and information developed concerning the distribution of potential general aviation demand within the study area, coincident with a determination of selected general aviation airport sites or areas – (as indicated in other sections) the following may serve to indicate the method to determine the relative potential general aviation demand that may be expected to be realized at the selected airport sites or areas.

A. Determine on the basis of actual survey, or other appropriate methods, whether accessibility has an effect upon the utilization of general aviation airports – the information requested should properly include the following:

1. name and address of aircraft owner – including street and zone number, if available
2. the local point of origin or destination before going to the airport of basing
3. the travel time with respect to the airport used – in minutes
4. the distance with respect to the airport used – in road miles

B. Determine the degree of effect, if any, that accessibility has upon the utilization of general aviation airports within the study area – the information, as noted in IV-A, should be analyzed in the following manner to determine the degree of effect that airport accessibility has upon the number of aircraft owners, within the study area:

1. determine the total number of aircraft owners
2. determine the total number of aircraft owners, by selected accessibility grouping from the airport of basing, in terms of:
   a. travel time
   b. distance
   c. travel time and distance
3. determine the average number of aircraft owners per selected measure of population, as adjusted for income differences, by selected accessibility groupings
4. determine through graphic analysis, whether the average number of aircraft owners, by accessibility grouping, indicates that accessibility does have an effect upon the number of general aviation aircraft owners.
5. if the analysis reveals an affirmative finding, then compute – graphically or by mathematical formulae – an expression of this effect of accessibility
6. prepare a "loss" table based on IV-B-5 indicating the effect of accessibility on the number of aircraft owners within the study area.

For illustration purposes, the degree of effect that airport accessibility has upon the utilization of general aviation airports in the Washington Study Area is presented below.

OBJECTIVE

Determine whether or not, airport accessibility and its related effect on general aviation airport utilization can be measured. This effect, if it can be measured, will indicate the degree of effect which should be applied to the distribution of the potential market that would be accommodated at selected airport sites or areas, to determine the realized potential general aviation demand at these airport sites or areas.

FINDINGS

It has been determined that there is a measurable effect upon the number of based aircraft that may be realized in the Washington Study Area, as the increments of accessibility - measured in terms of time plus distance - increase from the airport where general aviation aircraft are based.

CRITERIA

1. As previously mentioned, a survey of aircraft owners and users in the Washington Study Area was conducted during July through October, 1962. This survey information was obtained by interview, and through a mailing to all aircraft owners living within a forty nautical mile radius from Washington National Airport. These surveys, among other items requested the following:

   a. Airport where aircraft is currently based.

   b. Hours flown – last 12 months.

   c. Number of landings and take-offs – last 12 months.

   d. Local point of origin before going to airport (majority of trips).

   e. Local point of destination after leaving airport (majority of trips).

   f. Travel time and distance with respect to airport used:

      (a) From point of origin in the Washington Area: Time _____ Min., Distance ______________ Rd. Miles.

      (b) To point of destination in the Washington Area: Time _____ Min., Distance ______________ Rd. Miles.

   g. Please rank the following factors in order of their importance as to why your aircraft is based at the airport listed above:

	Rank
Accessibility	______
Safety	______
Services	______
Quality	______
Airport Rates and Charges	______
Others	______

2. The information was analyzed in the following manner to determine whether airport accessibility has a measurable effect upon the number of based aircraft in the Washington Study Area:

   a. determine the number of aircraft owners and users, based on survey forms returned,

   b. determine the total number of aircraft owners and users, by accessibility groupings (travel time plus distance) from the airport of basing,

   c. determine the average number of aircraft owners and users per 10,000 population, as adjusted for income, by accessibility grouping; reference Table VII,

   d. plot the data obtained in (c), determining on the basis of these plottings a line expressing the effect of travel time plus distance on the number of based aircraft in the Washington Study Area;

e. determine on the basis of the aforementioned graphical analyses, the per cent of the potential general aviation demand, in terms of based aircraft, that may be expected to be realized at selected airport sites or areas; the tabular presentation of this analysis is shown on Table VIII

DISTRIBUTION OF AIRCRAFT OWNERS-USERS/10,000 POPULATION TABLE VII

ADJUSTED FOR INCOME – BY ACCESSIBILITY GROUPING:

TIME AND DISTANCE TO AIRPORT OF BASING

WASHINGTON STUDY AREA

1962

Travel Time Plus Distance	Average Number of Aircraft Owners-Users/10,000 Population
0 - 10	1.96
11 - 20	1.68
21 - 30	1.53
31 - 40	.99
41 - 50	1.66
51 - 60	1.67
61 - 70	.73
71 - 80	.93
81 - 90	.42

Source: The average number of aircraft owners surveyed in the Washington Study Area, as adjusted for population and income grouped by the increments of accessibility from the airport of basing to the local point of origin or residence.

TABLE VIII

EFFECT OF TRAVEL TIME PLUS DISTANCE

ON THE NUMBER OF BASED AIRCRAFT

WASHINGTON STUDY AREA

Travel Time Plus Distance to Airport	Per cent of Potential Realized	Per cent of Potential Lost
0 - 10	100%	0%
11 - 20	92	8
21 - 30	84	16
31 - 40	76	24
41 - 50	68	32
51 - 60	61	39
61 - 70	53	47
71 - 80	44	56
81 - 90	36	64
91 - 100	26*	74
101 - 110	18*	82
111 - 120	11*	89

* Determined by graphic extrapolation

Source: Reading from Graph 1 with the values computed, using Index for 0 - 10 accessibility group = 100.

C. Determine the forecasts of realized potential general aviation demand, by selected airport sites or areas that may be expected, giving consideration to the effect of airport accessibility on the forecast distribution of potential general demand, within the study area — this determination should pursue the following steps for the study area:

1. determine the appropriate increments of accessibility from each of the census tracts or other areas within the study area to the selected airport sites or areas
2. determine for each census tract or other area the most accessible airport
3. apply the accessibility measurement to the "loss" table mentioned in (IV-B-6) to determine the per cent of potential that may be expected to be realized at the most accessible airport for each census tract or other area, within the study area
4. the per cent of the potential that may be expected to be realized for the selected airports should then be applied to the forecast distribution of aircraft owners, for each pertinent census tract or other area within the study area; this produces the forecasts of the relative potential general aviation demand that may be expected to be realized in the study area.

For illustration purposes, the forecasts of the realized potential general aviation demand by selected airport site areas in the Washington Study Area is presented below for 1970 and 1980. These forecasts give consideration to the effect of airport accessibility on the distribution of the potential general aviation demand in the Washington Study Area.

OBJECTIVE

Determine the forecasts of realized potential by selected airport site or area for general aviation demand, giving consideration to the effect of airport accessibility on the distribution of potential general aviation demand in the Washington Study Area, for 1970 and 1980.

FINDINGS

The forecasts of the Number of Based Aircraft for Airport Site Plan C, including Washington National and Dulles International Airports are presented below:

FORECAST – TABLE IX

BASED AIRCRAFT – AIRPORT SITE PLAN C

WASHINGTON NATIONAL AND DULLES INTERNATIONAL AIRPORTS

WASHINGTON STUDY AREA

1970 - 1980

Period (1)	Washington National Airport (2)	Dulles International Airport (3)	C-1 (4)	C-2 (5)	C-3 (6)	C-4 (7)	Total (8)
1970	57	23	122	141	32	303	678
1980	74	29	160	184	42	394	883

Source: Columns (1) and (2) – Washington National is restricted to the volumes shown due to indicated capacity limitations by the Federal Aviation Agency.

(3), (4), (5), (6) and (7) - Application of Total Relative Based Aircraft Potential to Tables VI and VIII based on most accessible for each survey district and/or statistical area within the Washington Standard Metropolitan Statistical Area.

(8) - Sum of Columns (2) through (7).

CRITERIA

1. The following determinations were made to develop the forecast of the realized potential general aviation demand, in terms of based aircraft, for airport site plan C in the Washington Study Area:

   a. determine the increments of accessibility – travel time and distance – from each survey district and statistical area to each airport under site plan C, including Washington National and Dulles International Airports,

   b. the summation of travel time plus distance from each survey district and statistical area to the most accessible airport or airport site was determined for each airport under site plan C,

   c. for airport site plan C, Washington National Airport was restricted due to indicated capacity limitations by the Federal Aviation Agency,

   d. having determined the most accessible airport from each survey district or statistical area, for airport site plan C, the increment of travel time plus distance was then applied to Table VIII to determine the per cent of the potential that may be expected to be realized at the most accessible airport from each survey district or statistical area,

   e. the per cent of the potential expected to be realized for each airport site or area – under plan C was then applied to the forecast distribution of based aircraft for each pertinent survey district or statistical area in the Washington Study Area, in 1970 and 1980, as noted on Table VI,

   f. the number of based aircraft for airport site plan C – and for each airport site or area within this plan – was determined; these forecasts are shown on Table IX.